NBSIR 84-2939

Criteria for Mechanical Systems in Multifamily Buildings for Residential Weatherization Options

Lawrence S. Galowin

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
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Gaithersburg, MD 20899

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The National Bureau of Standards (NBS) prepared the original criteria and list of eligible retrofit options adopted for energy conservation by the Department of Energy (DoE) Weatherization Assistance Program (WAP) regulation under the Energy Conservation in Existing Buildings Act of 1976. NBS was requested to review, update, and expand the criteria and list of retrofits for 1984 amendments to the regulation. This report presents the criteria and reference standards for retrofit options of mechanical equipment and systems in multifamily buildings.

Mechanical systems equipment, controls, energy management systems, burners, and boiler/furnace tuneup/repairs were included. The options for retrofit technologies for equipment replacement components include items such as burners, burner controls, combustion chamber refractories, modifications with dampers, turbulators, and waste heat recovery devices. The criteria developed did not include economic factors and statutory constraints under the rulemaking procedures.

Key words: boiler/furnace performance upgrading; energy controls; energy conservation; mechanical building equipment; replacement burners; weatherization; tuneups and repairs for multifamily building equipment.

Disclaimer -- Names of manufactured items do not indicate endorsement or evaluation of products; such identification illustrates representative examples.

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1. INTRODUCTION

1.1 BACKGROUND

The Weatherization Assistance Program (WAP) was established under the Energy Conservation in Existing Buildings Act of 1976, as amended, to provide assistance to low-income persons and to reduce national energy consumption. Funds are allocated under the WAP to States, the District of Columbia and Indian tribal organizations (under certain circumstances). Within those jurisdictions distributions of funds are made to local governments, nonprofit organizations and tribal groups to perform weatherization retrofits and activities. Funds are allocated to the states using a formula which is based upon the numbers of low-income households in each state, the annual heating and cooling degree days, and the percentage of total residential energy used for space heating and cooling.

In January 1984, the Department of Energy (DoE) adopted amendments to the regulation for the program to improve its efficiency and effectiveness. Among the changes adopted were an expanded list of eligible measures which now encompasses options for mechanical equipment, including multifamily buildings*. The definition of "Weatherization Materials" now includes several new products, systems components, and materials. Further, appendix A of the regulation was revised to incorporate a listing of applicable standards for additional adopted measures.

The National Bureau of Standards prepared the expanded criteria, to support the revisions to the measures list and appendix A, adopted in the final rule published in the Federal Register, January 27, 1984. This report discusses the retrofits applicable for multifamily building mechanical equipment. The provisions tabulated in this report established recommended WAP criteria for mechanical equipment and systems in the DoE update of the regulations. The new retrofit criteria published for materials used as "Architectural" options and mechanical equipment options for single-family residences in are presented in [2] and [3], respectively. As used here, the term retrofit means the process whereby materials, components of systems, and products are permanently added to single-family and multifamily residential dwelling units or homes in order to reduce heating and cooling energy consumption. Also, certain modifications, repairs, tune-up adjustments, and component cleaning are included as measures for improving performance of existing equipment although no standards or specifications prescribe the procedures, training, licensing, and experience are required. The expanded categories for specific eligible weatherization measures permit a comprehensive approach for energy savings beyond the earlier "architectural" measures which functioned primarily to reduce air infiltration through the building envelope and provide increased thermal insulation [1].

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* Amendments to the proposed rules for public comment were announced in the Federal Register, Vol. 48, No. 215, November 4, 1983. Final rule amending the regulation was published in the Federal Register, Vol. 49, No. 19, January 27, 1984.

1.2 PROFILE OF MULTIFAMILY BUILDINGS

The multifamily building sector in the United States residential housing stock was reported in a study of the residential energy market sponsored by the Gas Research Institute [4]. From that report, information has been summarized to provide a background for multifamily building energy conservation opportunities.

The multifamily sector represents approximately 13 million rental units which consume about one quad of energy per year (1 quad = 10^{15} Btu). According to the Annual Housing Survey of 1978, 82 percent of the apartments are renter occupied. The multifamily buildings considered in the statistics [4] were for five or more apartments. In ASHRAE Standard 100.2P, "Energy Conservation in Existing Buildings: High-Rise Residential," building classifications are subdivided into Low Level Residential not more than three stories in height, and High-Rise Residential-more than three stories. The geographical distributions of apartment buildings are: Northeast Census Region contains about 30 percent, Southern Census Region about 26 percent, and the North Central and Western Regions about 22 percent each.

In multifamily rental units, energy usage has become a major part of operating cost. Building owners and managers have little incentive for investment because of constraints from local conditions of rent control, taxes on improvements through higher assessments, and local building regulations that require considerable overall systems upgrading when making any single component retrofit. There is a trend toward individual metering for utility consumption in each rental unit (31 states have considered banning master metering for gas and electric services in new buildings).

The estimated national average for the number of apartments in buildings is 14 units per multifamily structure. In figure 1.1 the distributions of apartments by size (based on the Census Regions) are shown. The non-uniform distributions of apartment compositions for building sizes in different parts of the United States are indicated. Construction of multifamily structures has had a strong growth pattern since 1950. About two-thirds of existing apartment buildings were constructed since 1950 and one-half of existing apartment buildings are less than 20 years old (an average single-family home is 27 years old). In figure 1.2 the growth of the multifamily housing stock is shown for renter-occupied units since 1970. Small apartment buildings, those with fewer than 20 units, comprised 73 percent of the net addition of all apartment units from 1970 to 1978; buildings containing 5 to 9 units represented about one-half of the total growth in the same period. Demand for multifamily rental and condominium units were attributed to: growth in the early family, individuals in the under 35 year age group and the over 65 year age group; long-term social patterns of declining birth rates leading to smaller average household sizes; and continued increases in the costs of owning single-family homes.

1.3 MULTIFAMILY BUILDINGS ENERGY USAGE

The multifamily buildings sector is distinguished from other residential stock by its composition, size, and geographical concentrations. Apartment units and common areas used 930 trillion Btu's of energy in 1978. A comparison of household energy usage in residential buildings is shown in figure 1.3. The average apartment annually consumes 43 percent less energy than the average single-family detached home. This lower energy usage per unit is due, in part, to the smaller size living units. The national average size for rentable apartments is 850 square feet compared with about 1,500 square feet for single-family homes. Apartment units within a single building envelope (with lower ratios of surface to volume ratios than single-family homes) benefit somewhat from adjacent occupied apart ments in lowering energy losses. The correlations between household income and energy use indicates that lower incomes would be associated with lower energy consumption. For residential units on a square-footage basis, single-family house use about 104,000 Btu/ft^2/year and apartments use about 96,000 Btu/ft^2/year.

The pattern of energy load distributions in multifamily units differs from those in single-family homes. In figure 1.4 the distributions for energy end-use are illustrated. For high-rise multifamily units 55 percent of the total amount of energy is used for space heating and cooling while a single-family detached house uses 70 percent of the total energy for the space conditioning. A larger part of the energy budget in multifamily housing is expended for heating water; the 30 percent level is twice that for single-family detached units. The percentages of the various fuels used to meet the energy needs of the residential sector are shown in figure 1.5. Following gas as the foremost fuel, oil is the second most preferred fuel in the multifamily buildings. The distribution of fuels used for heating rental apartments in the U.S. Census Regions are shown in figure 1.6. Dependence on oil is dominant in the northeast region whereas in other regions gas or electricity is the principal energy source. Within multifamily buildings the variations of fuel types with building size are shown in figure 1.7. For buildings with 20 units, the percentage of oil usage is greatest while for buildings with up to 19 units gas is the most commonly used fuel.

Within multifamily buildings the different end use purposes for various fuels vary as shown by the bar chart of figure 1.8. Of the total amount of energy about 53 percent was used for space heating, 30 percent for water heating, and the remainder for all other applications (the estimates for 1978 were based on the DoE consumption model which dates back to 1974 and on survey data for 1978 to 1979). Hot water requirements of occupants in any type residential facility are similar; consequently with lower total energy usage in apartments the portion of energy consumed for hot water would represent a larger fraction (as seen is figure 1.4). Hot water energy consumption represents a target in retrofit energy conservation measures, and these measures can be coupled with water conservation techniques to further reduce energy usage.

Centrally heated multifamily units represent 44 percent of the national rental units, the others are heated by individual systems.* Figure 1.9 shows the

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* Equipment for retrofit within individual apartment systems would follow recommendations and criteria cited by the WAP from for single-family residences [3].

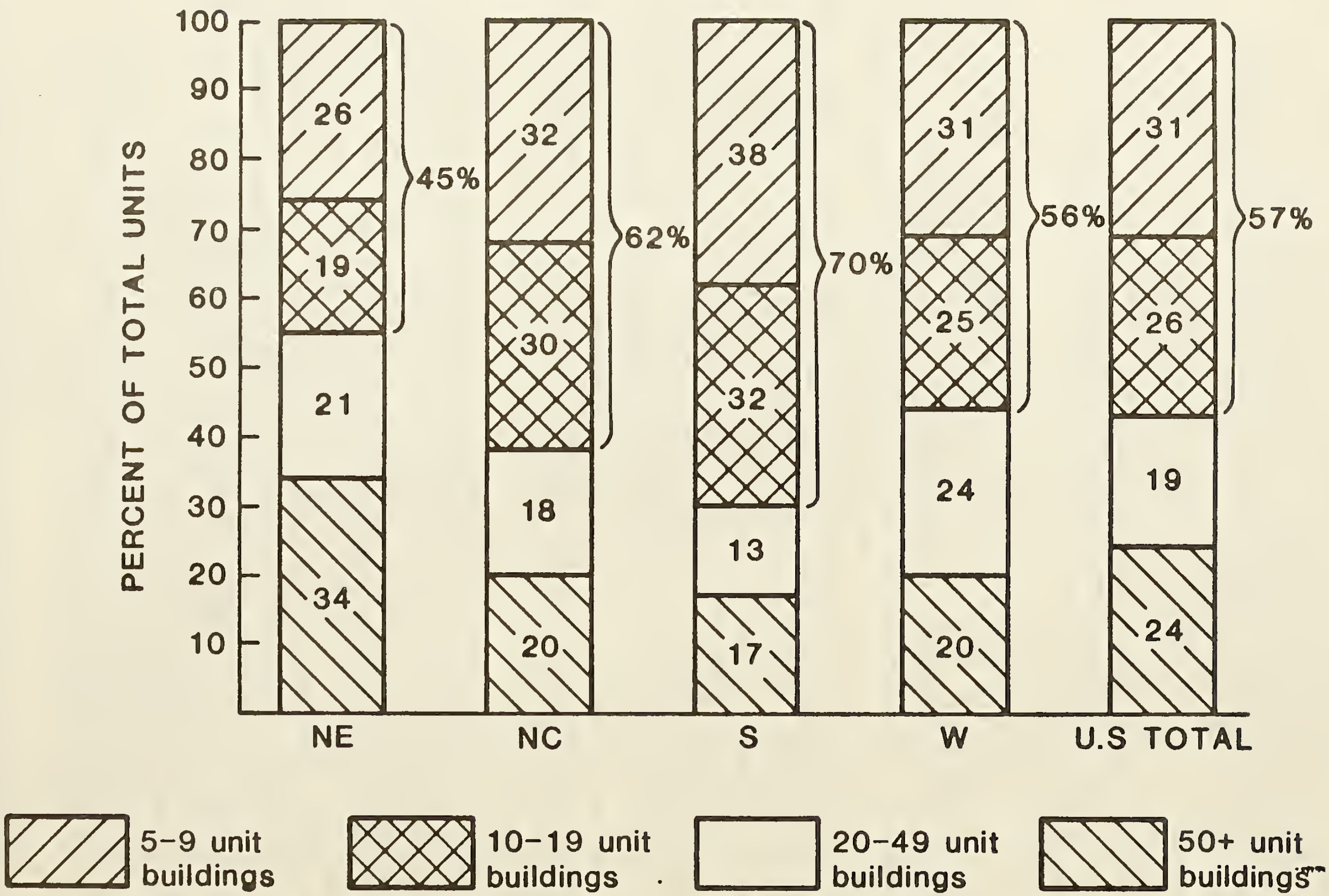

Figure 1.1. Composition of the multifamily by building size (1978)

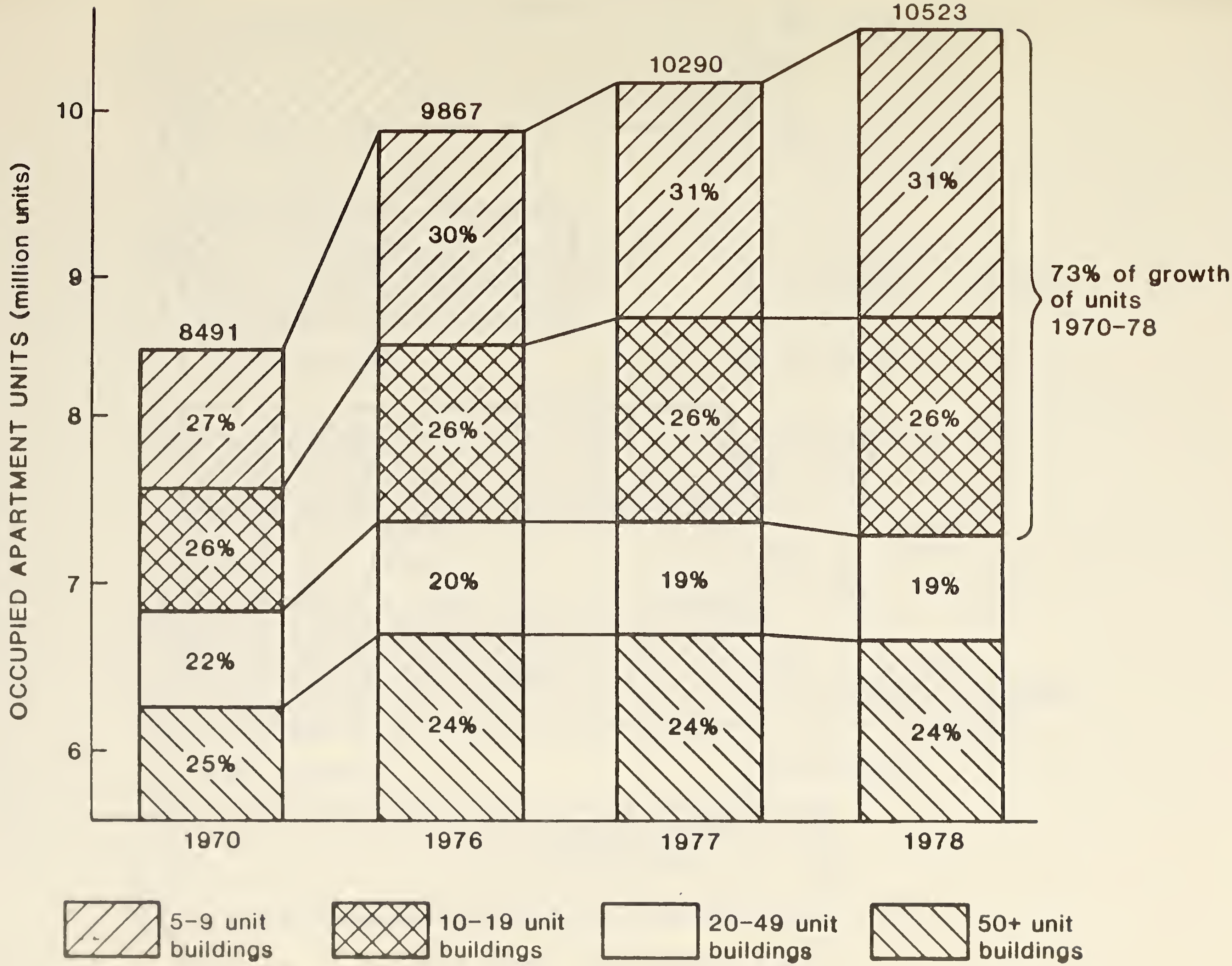

Figure 1.2. Growth of the multifamily housing stock

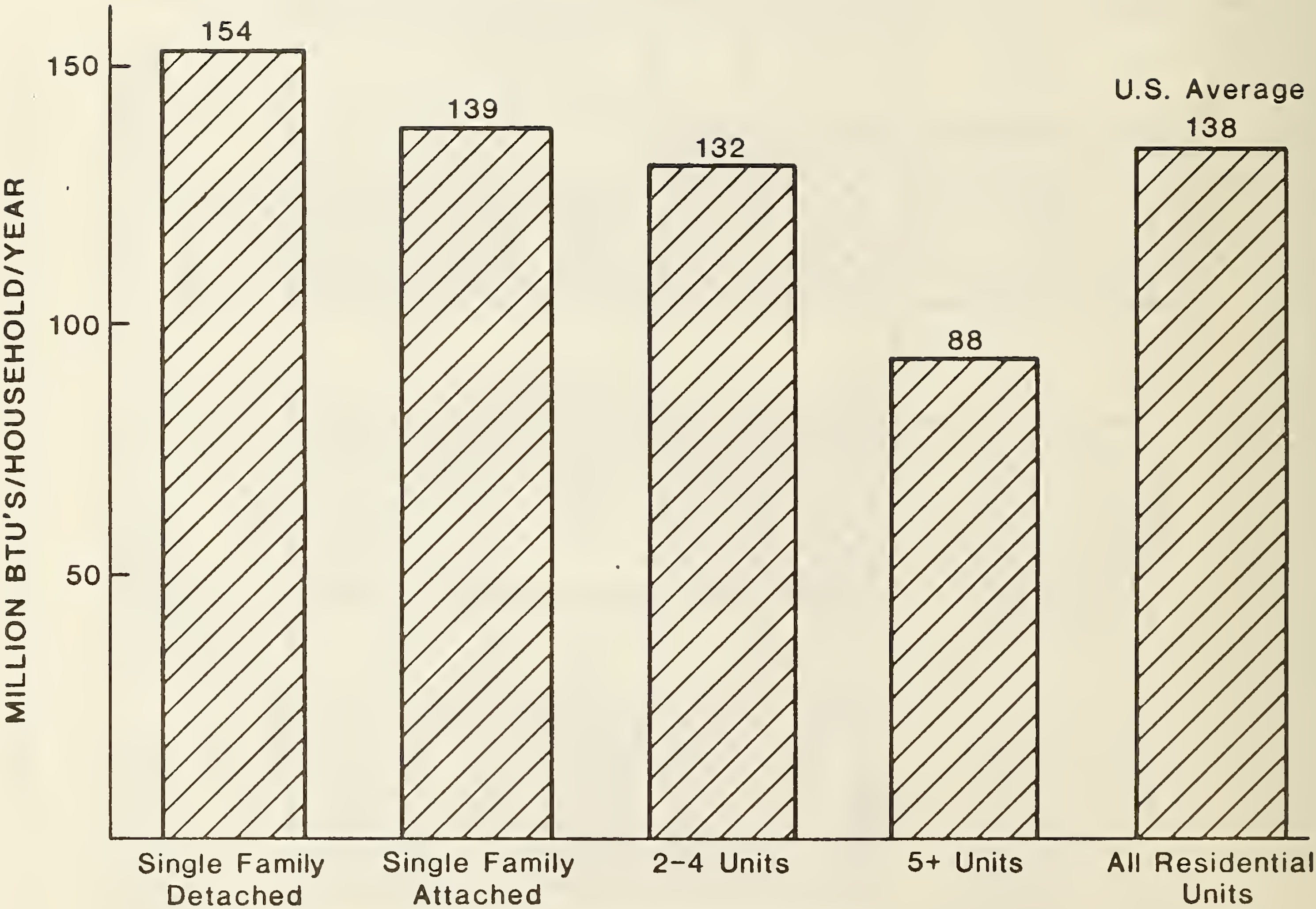

Figure 1.3. Household energy consumption, 1978-1979

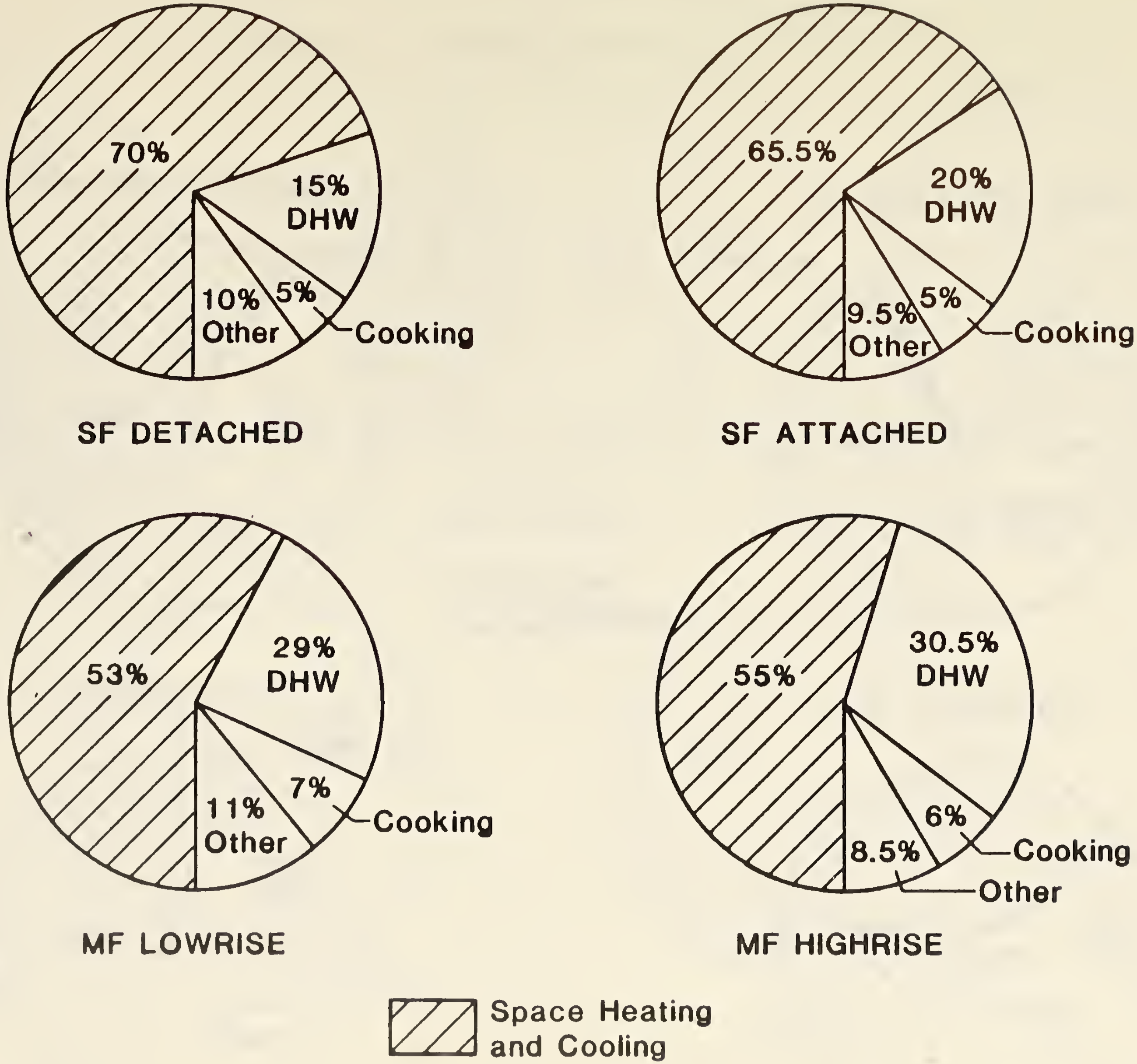

Figure 1.4. Functional end by residential structure type

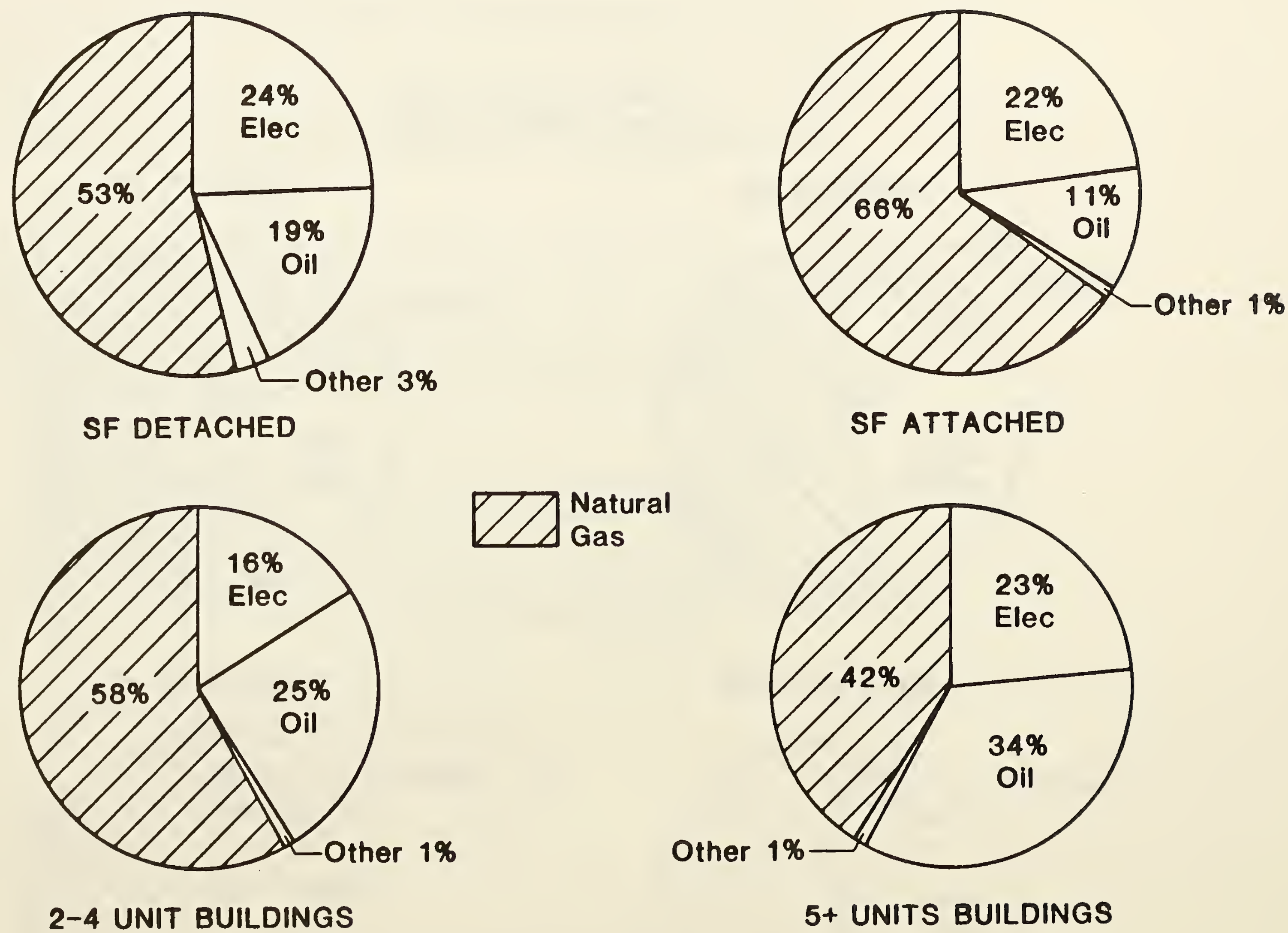

Figure 1.5. Percent of total Btu

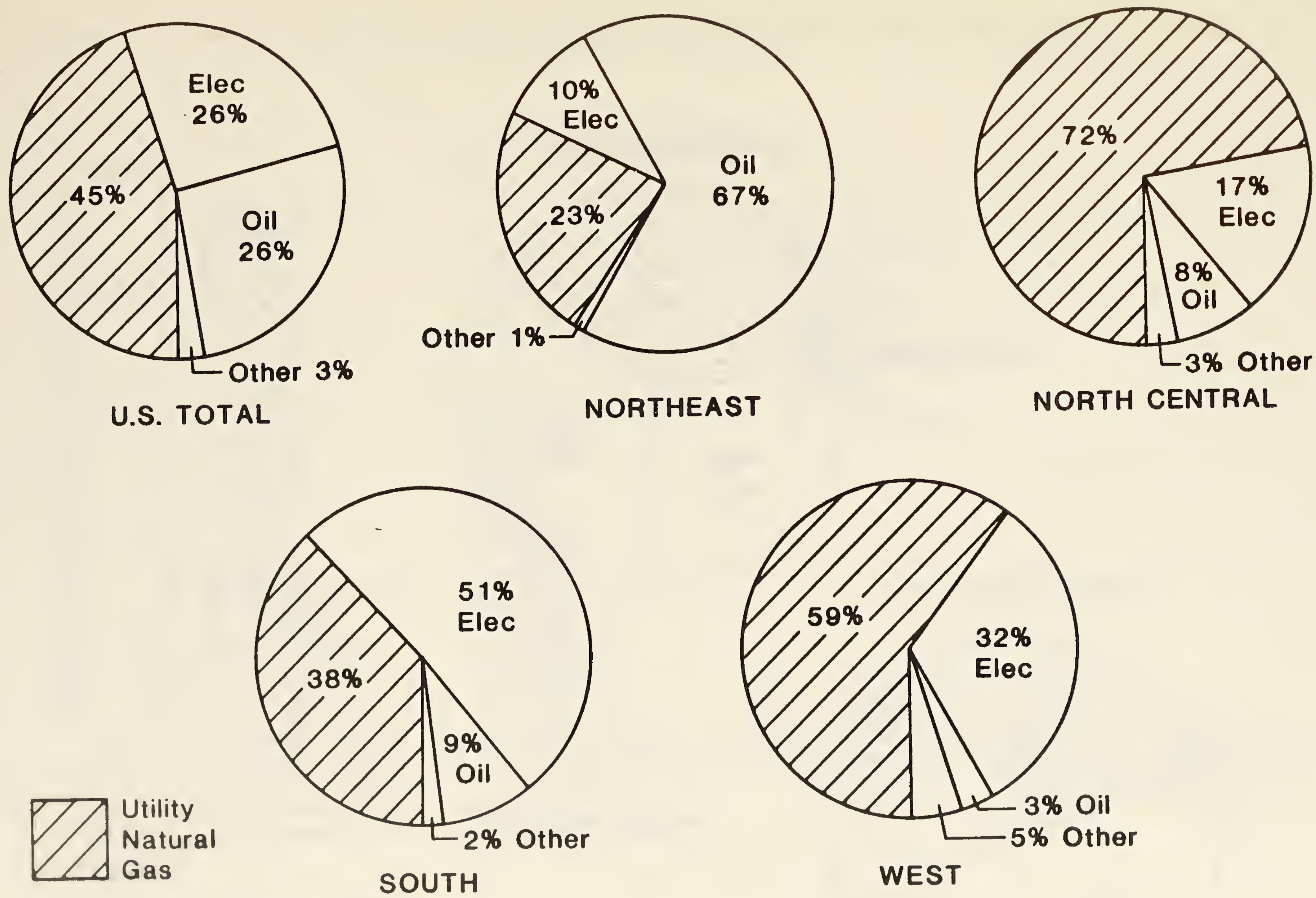

Figure 1.6. Percent of rental apartment units using various heating fuels, by region

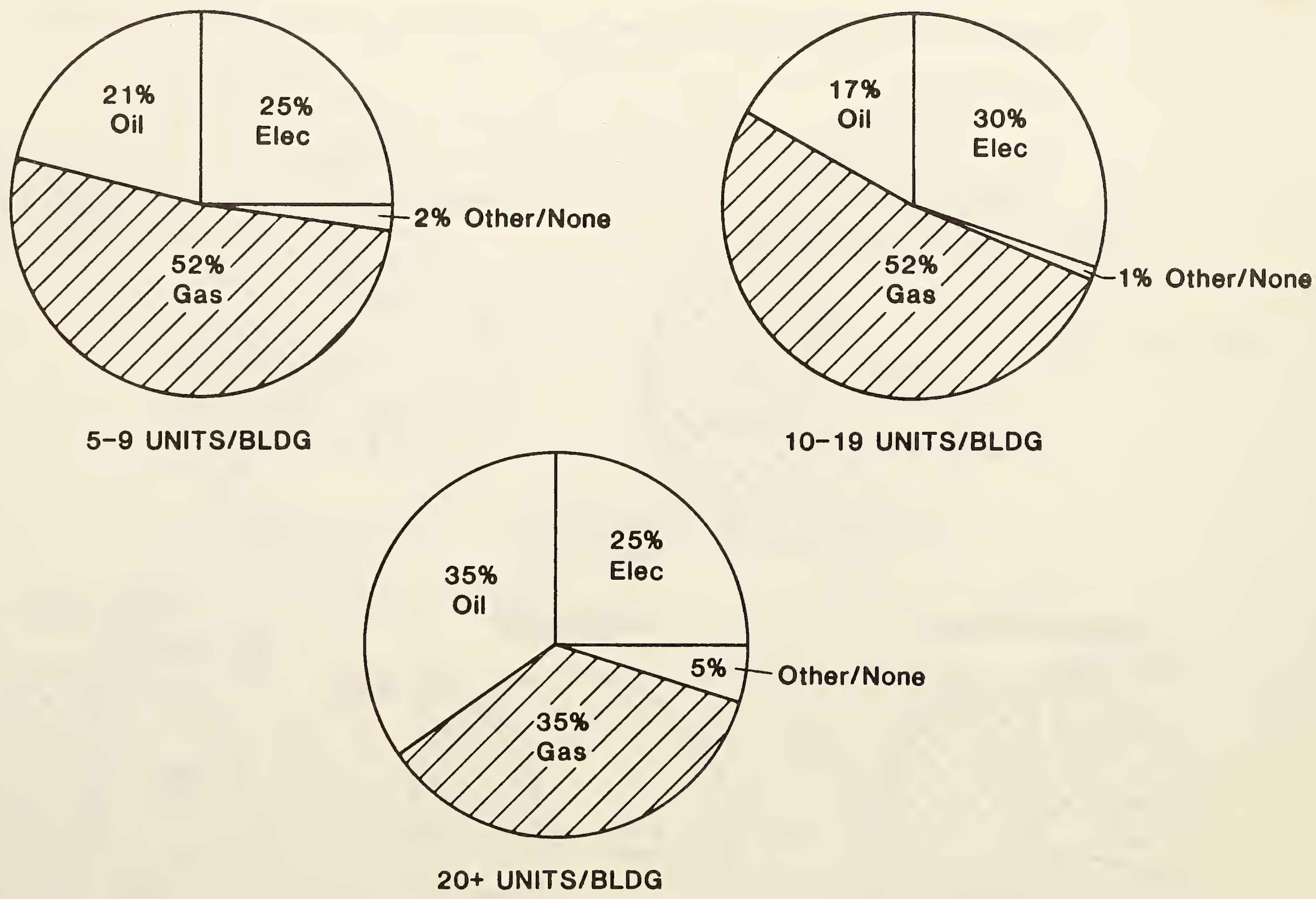

Figure 1.7. Heating fuel by multifamily building size (percent of units using various fuels for heating)

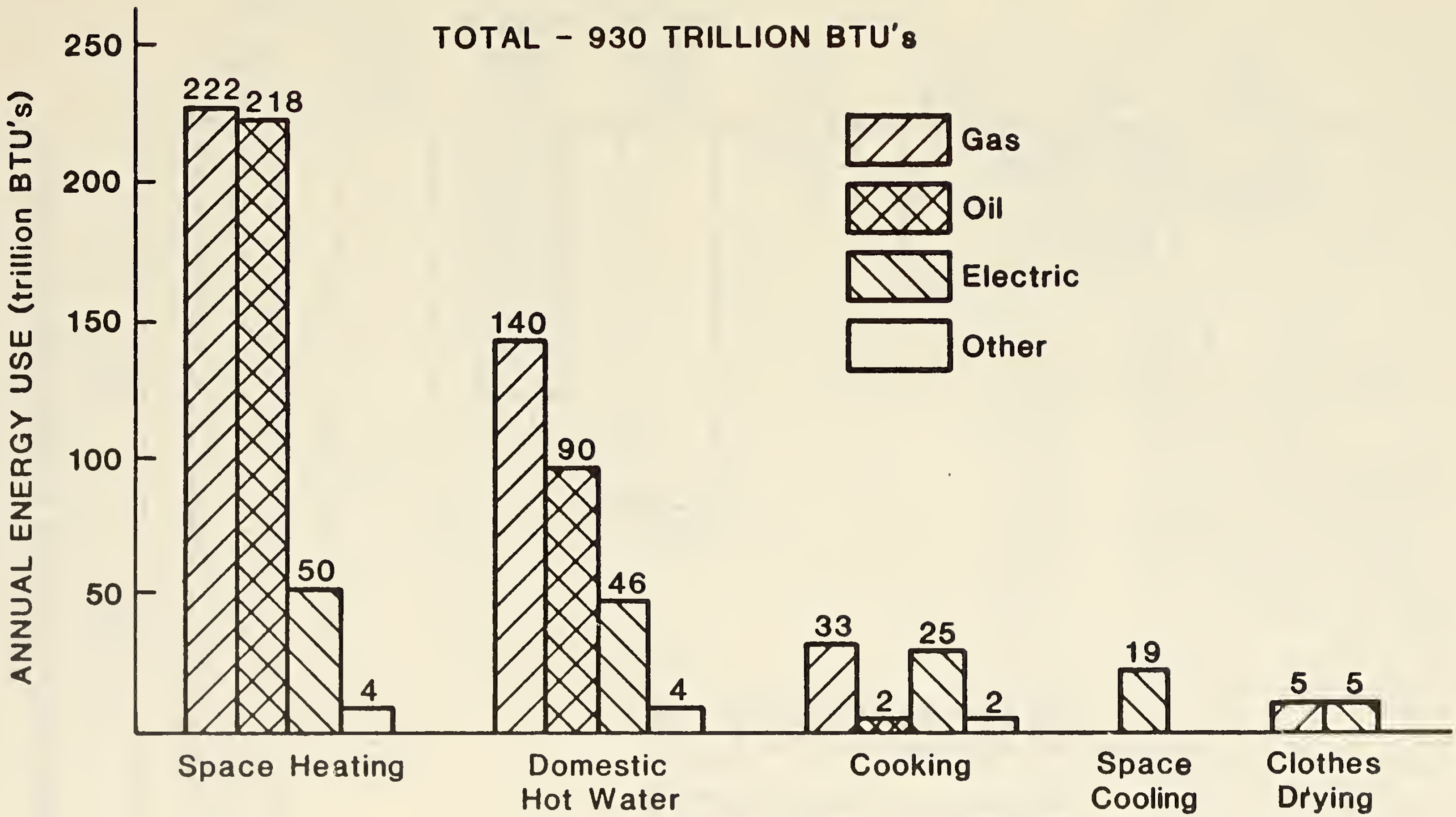

Figure 1.8. Functional end-use of energy in apartments and fuel share (1978)

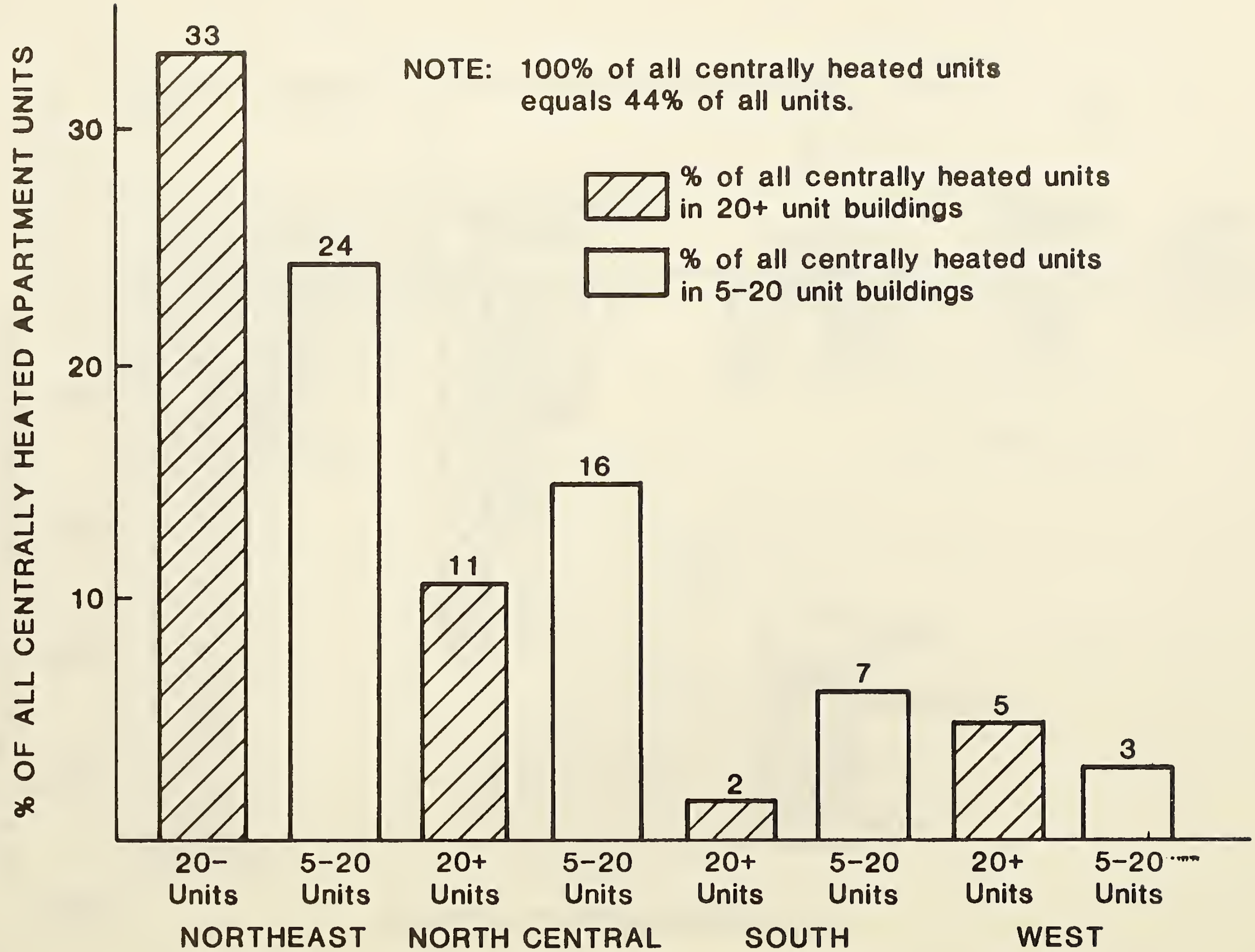

Figure 1.9. Central heating systems by region and building size (1977)

distribution of central systems by region and building size. The northeast has 57 percent of the Nation's apartment buildings; buildings with 20 or more units comprise 58 percent of centrally heated buildings. The types of equipment used for central and individual heating in multifamily rental units are shown in figure 1.10. The central systems are primarily steam or hydronic systems with 6 percent warm air furnaces older in smaller apartments. Warm air furnaces represent 55 percent of the individual heating systems with 23 percent in the form of electric resistance devices. The other types of individual unit systems are wall or floor furnaces, room heaters, fireplaces, stoves, and portable heaters. In figure 1.11 it is shown that central steam and hot water systems are located primarily in larger apartment buildings. Warm air furnaces are the most common in individual unit heating systems and also appear to be concentrated in smaller apartment buildings.

The utility bills for multifamily operations are more than one-quarter of the total operating expenses. Figure 1.12 indicates the increased costs of heating fuel from 1974 to 1979; gas, electric, and oil increased by 27, 14, and 13 percent, respectively.

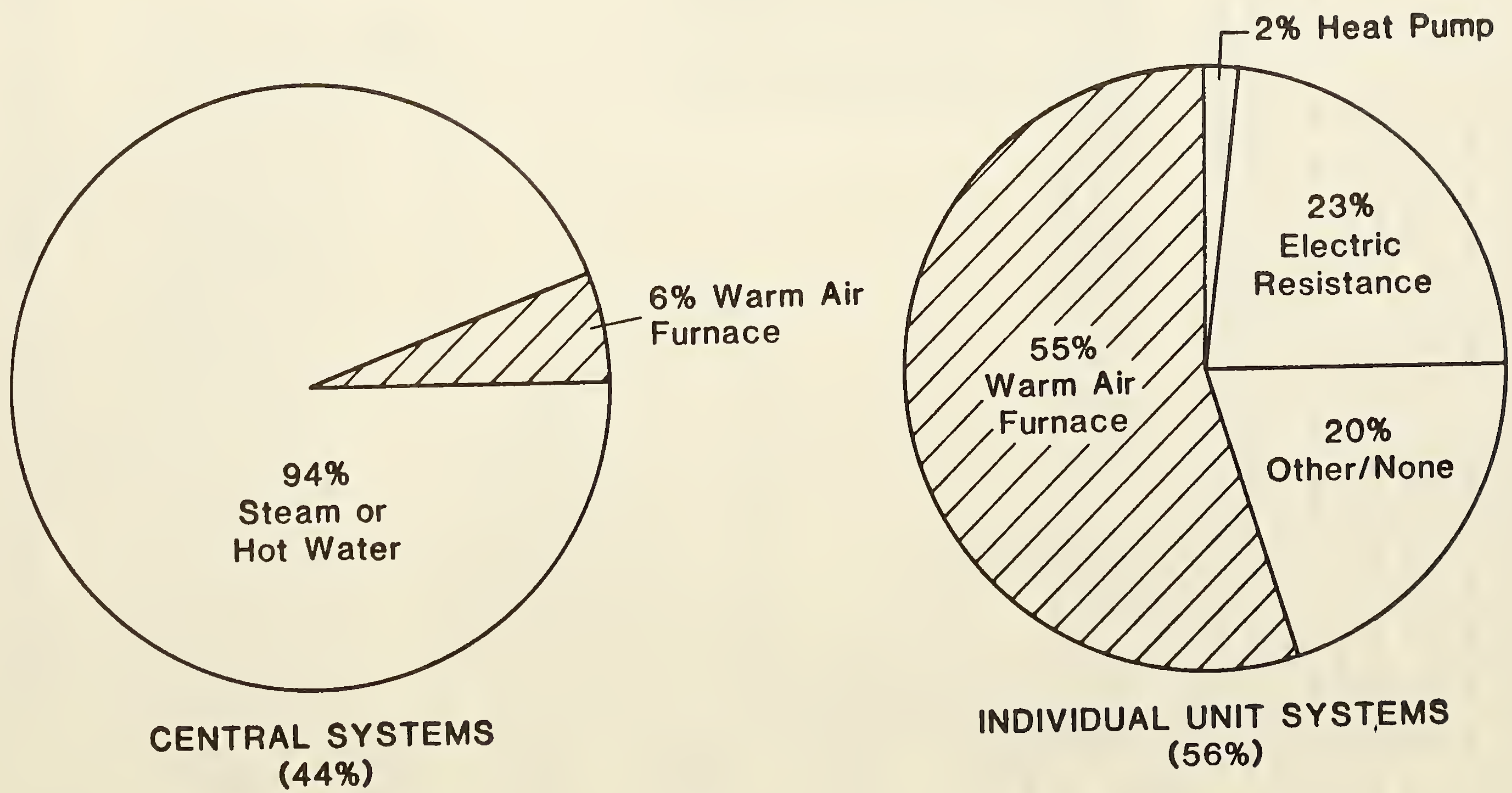

Figure 1.10. Multifamily rental units by heating system type

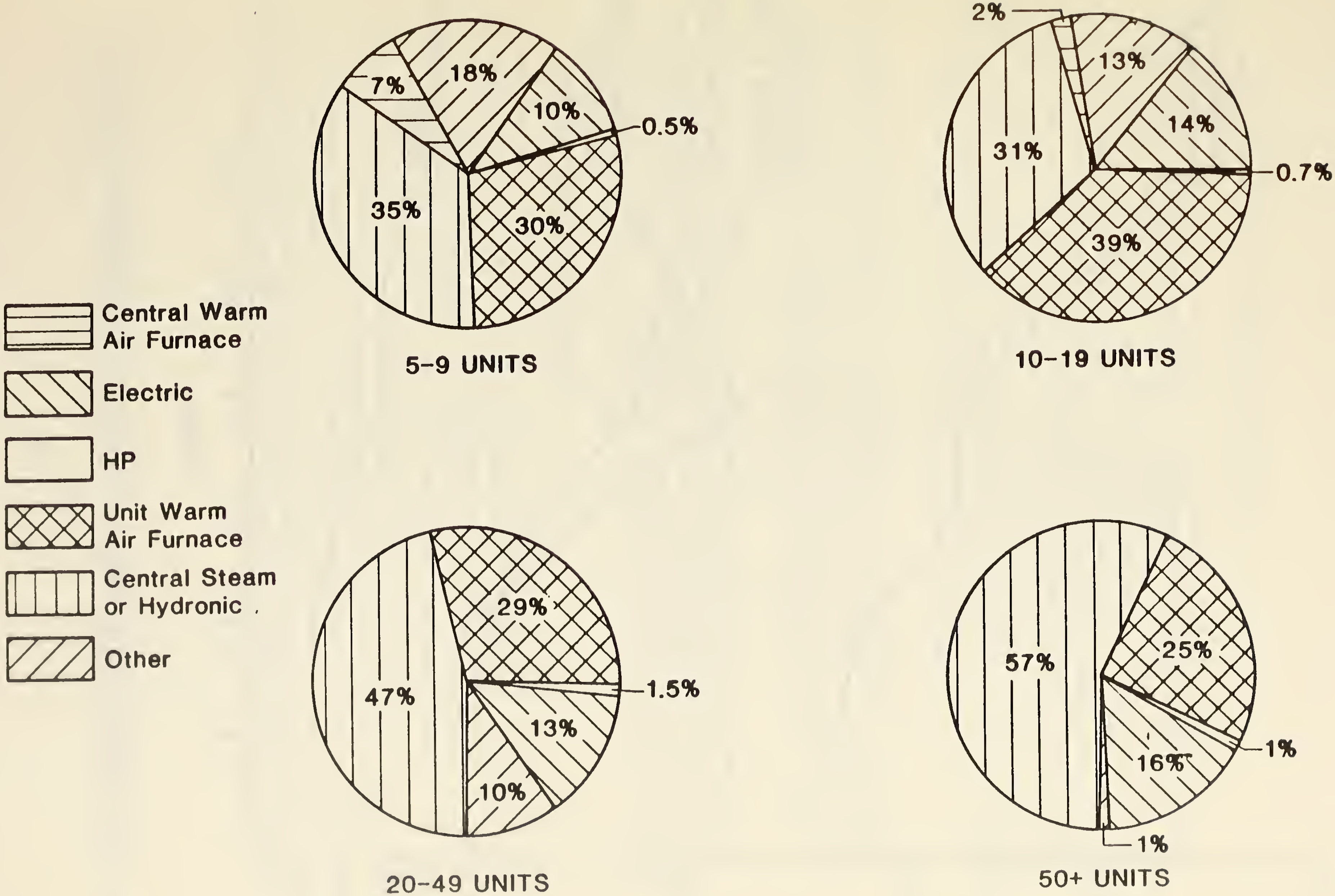

Figure 1.11. Multifamily rental units by building size

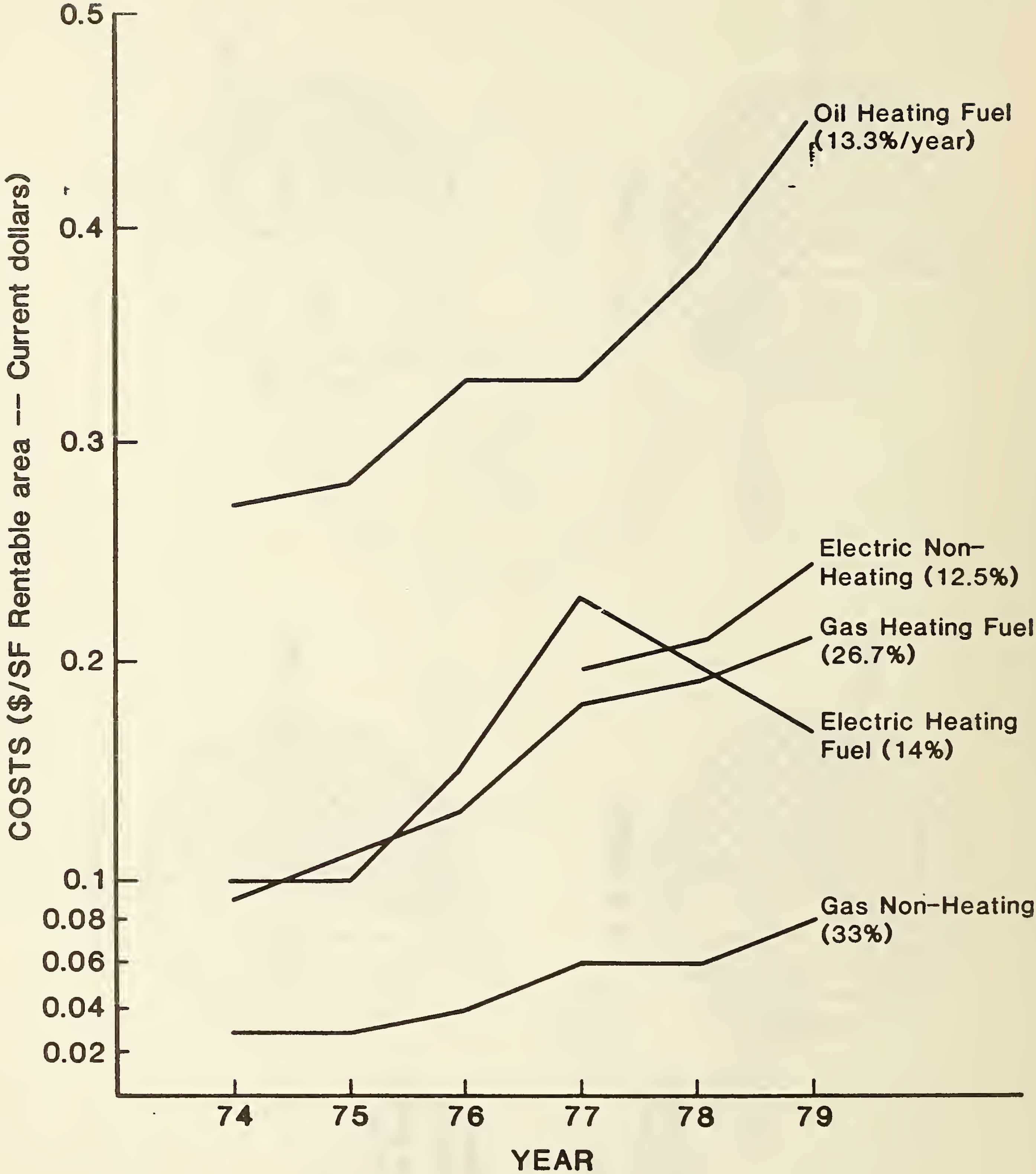

Figure 1.12. Reported utility costs in apartment buildings (current dollars)

2. ENERGY EQUIPMENT IN MULTIFAMILY RESIDENCES

Energy usage patterns for occupants in multifamily dwelling units and single-family residences are similar. The greatest amount of end-use energy in multifamily dwellings is for space conditioning, at about 55 percent of the total energy. The next most important energy end use is for water heating, about 30 percent (that percentage is approximately twice that for single-family residential energy usage). The total energy consumed in apartments with multifamily usage is less than for single-family buildings; consequently, water heating becomes a larger fraction of all the energy used. That is because water load patterns for occupants are not altered by the size of the building. Other energy consumption is approximately 5 percent each for lighting, cooking, and refrigeration (with clothes drying, garbage disposal, television, fans, and other small appliances included as miscellaneous items).

The criteria for weatherization as discussed in other reports [1, 2, 3] are applicable and independent of the building size when individual apartment units have installed unitary equipment comparable to those in single-family residences. Those retrofits measures include windows, walls, caulking, and appliances or other dwelling equipment (including special service rooms or basements equipped for laundry and drying).

In this weatherization study of multifamily buildings the requirements considered were primarily for central systems used for space conditioning and domestic hot water heating systems. Space conditioning and hot water systems of multifamily buildings represent the largest energy usage (about 85 percent) in apartment buildings. Descriptions of various types of installed equipment are provided in the following sections.

2.1 CENTRAL SYSTEMS AND COMPONENTS

Central systems supply conditioned water, steam, or air through pipes and ducts for heating and cooling of individual apartments from a large furnace, boiler, chiller, or air-conditioner. Some systems employ large conditioned hot or cold water storage holding tanks. The mechanical equipment is typically located in the basement and high-rise buildings mechanical components may be located in an equipment penthouse. Local building codes often prohibit central recirculating air systems in apartment buidings since it is considered undesirable to mix return air from many occupied units (cooking odors, germs, smoking products are of concern). Thermal exchange through heat emitters (radiators, finned tube baseboards, etc.) at the point of use from the heat transport media provides the energy within the occupied space. Steam, hot water, and/or anti-freeze liquids are used to circulate the energy contained in the working fluid. The ASHRAE Guide and Data Book* provide schematics and descriptions

* Older volumes contain material appropriate to the times of construction and installation of equipment in buildings that are probable condidates for weatherization.

of various central systems, distribution methods, and various applications of controls for safety and performance.

2.1.1 Steam Distribution Systems

Steam distribution systems for operation below 15 psig (pounds per square inch, gauge) are classified as low pressure, and those for operation above 15 psig as high pressure.* Steam heating systems are identified as the gravity circulation type when condensate returns under its own hydraulic head and the mechanical circulation type when condensate water is returned by a pump. Those systems are further specified as upfeed, when the supply main is below the heat emitter and downfeed when the supply main is above the heat emitter. Additional classification of steam systems are known as one-pipe or two-pipe (or more) depending upon whether the steam and condensate are carried in the same pipe or separate pipes (additional numbers of pipes may appear when chilled water is circulated).

The one-pipe system carries steam and condensate to and from the boiler and through the radiator or baseboard element in the same pipe. The original heating systems in many older buildings were of the single-pipe steam type. A typical one-pipe air vent system is shown in figure 2.1 with a common air vent in the return line. The individual radiators require a steam air vent (venting to atmosphere) which may be controlled by a thermostatic element and a supply radiator valve on each unit (and can be the same type of valve normally used for two-pipe systems). Vacuum breaker air vents must be installed on risers of the steam system.

Boiler operation is initiated by a sensor/controller in a representative building or apartment zone, or by a timer. Steam is delivered by the piping distribution system. The radiator air vent valve permits contained air to be displaced (eliminated) while the steam enters. The thermostatic valve element closes when sufficiently heated. As the steam cools in the radiator the condensate forms and flows out of the radiator permitting more steam to enter. The radiator fills with steam and remains hot when the air vent valve is closed and latent heat is released from the condensing steam. During cooldown (or off cycle -- the boiler may be shutdown) the air vent valve permits air to enter the radiator while the remaining condensate returns to the boiler. Proper operation requires that the interior pressure (gauge) returns to zero during the off cycle. A controller on the return line assures that all the steam is condensed when the pressure is essentially zero. Vacuum breakers or quick air vents open to atmosphere when there is no pressure in the system to avoid suction pressures and pull back of steam upon resumption of operation. Retrofits for steam systems with thermostatic valves require selection of devices and installation based upon manufacturer specifications and procedures.

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* Older equipment installations in buildings are the component and equipment issues in this report; consequently specifications, displays of identification markings and display tags will be shown in nonmetric units that would be imprinted thereon.

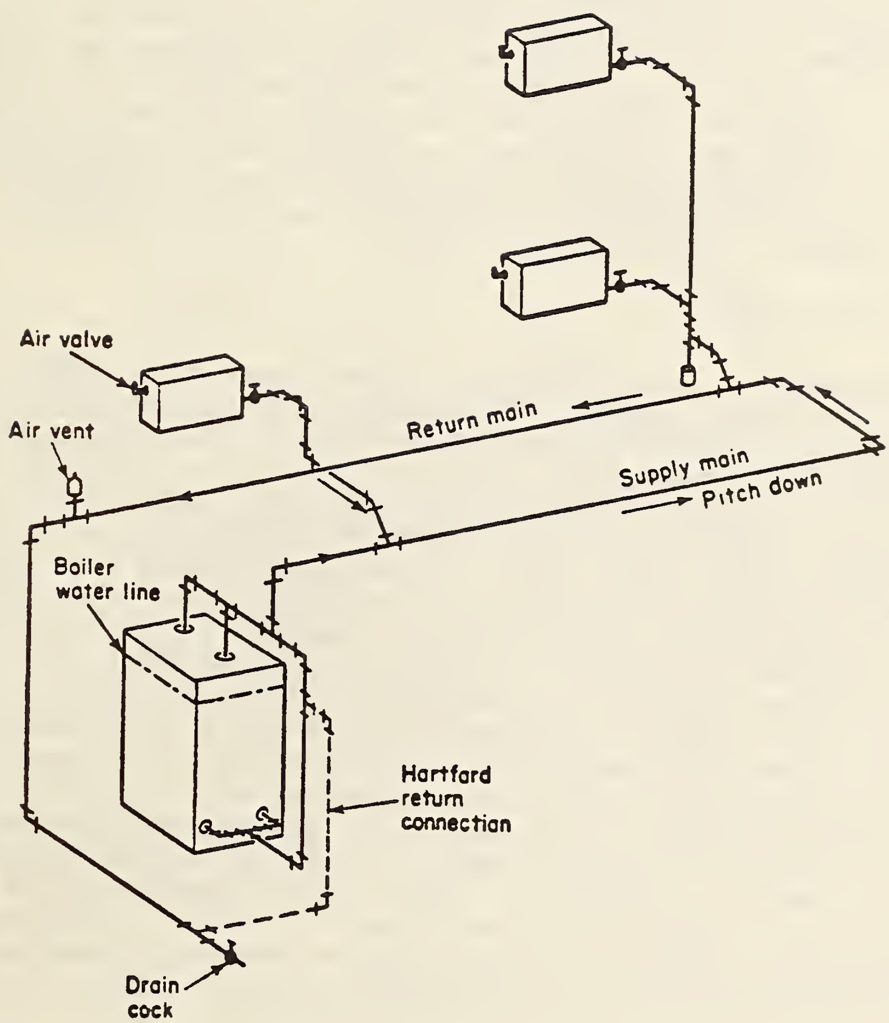

Figure 2.1. Typical upfeed gravity one-pipe air vent system

Improperly cycled boiler operation will cause either excessive heat or lack of heat depending on the time constant of the system. If the radiator is flooded with water (from earlier cycle condensate) because return flow is prevented by high velocity entry steam at the radiator inlet valve (due to undersizing) no steam will enter and the radiator will remain cold. Flooded backed up radiator conditions will cause new water makeup (additional water due to lowered level) addition to the boiler and subsequently cause the boiler to flood.

Vacuum return systems are two-pipe systems in which a vacuum return pump creates a low-pressure in a condensate receiver connected to the return line. At the return pump the water and air are separated, with the water returned to the boiler and air discharged to the atmosphere. Subatmospheric systems regulate steam flow into the main by a supply throttle valve controlled by an automatic thermostatic control, and maintains fixed vacuum differential between supply and return lines by a differential controller. Condensate-pump systems use water pumps in place of vacuum return pumps; they are found in systems for extended surface heating coils and in limited size distribution piping for direct radiation (panels, surface coils).

2.1.2 Hot Water Heating Systems

Hot water heating systems or central hydronic systems have two-, three-, or four-pipe water distribution systems. These systems can include cooling and heating for space conditioning (with appropriate boilers, chillers, controls, and valves). One-pipe may mean either a loop or supply main, with heat emitters in a series circuit, or the loop main with diverting fittings at branch takeoff points. The two-pipe system has one common central supply pipe and one return pipe for all apartment units. The three- and four-pipe systems are applied for chilled water supply and hot water supply with either a common return pipe or separate (hot and chilled) water return lines. Examples of installed systems are indicated in figures 2.2 and 2.3. In operation the hot water circulation may be controlled by one or more pumps depending on the system design. Design supply temperatures above 250°F are frequently designated as high temperature hot water (HTHW) systems which are found in larger individual and central system applications. Operating design supply temperatures up to 325°F are designed for operating pressures of 125 psig. The requirements* for equipment/accessories installations of the heat generator (existing or replacement boilers, furnaces) should be according to those originally certified by their manufacturers (see later discussion of fuel types). Pressure vessel requirements and provisions for repair to maintain pressure integrity should be in accordance with the American Society of Mechanical Engineers (ASME) Pressure Vessel Code.

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* Older building equipment installations were subject to practices, regulations, and requirements which may be different from current local jurisdiction building codes. Changes, replacement, or modifications may be locally regulated to require that other mechanical systems/components be upgraded. Such requirements and approvals for mechanical system changes should be determined.

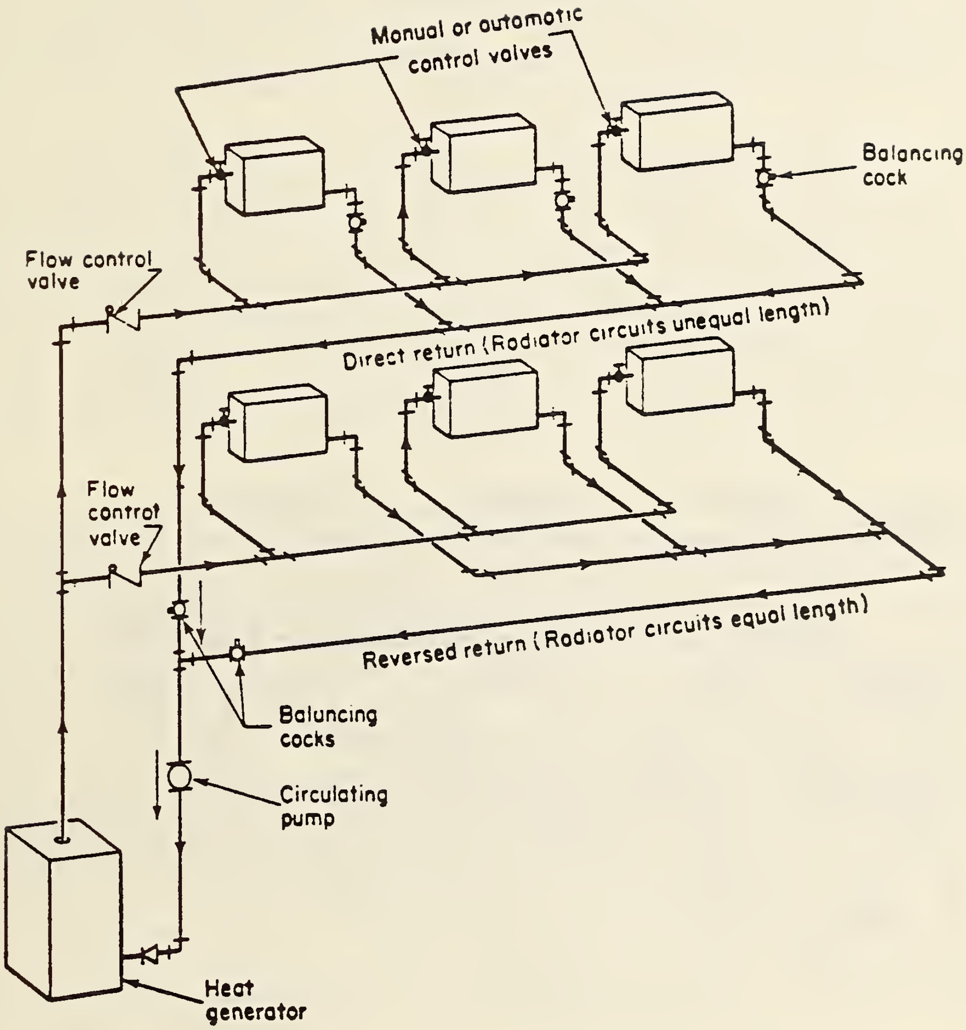

Figure 2.2. Hot water system with one circuit having a direct return and one circuit having a reversed return

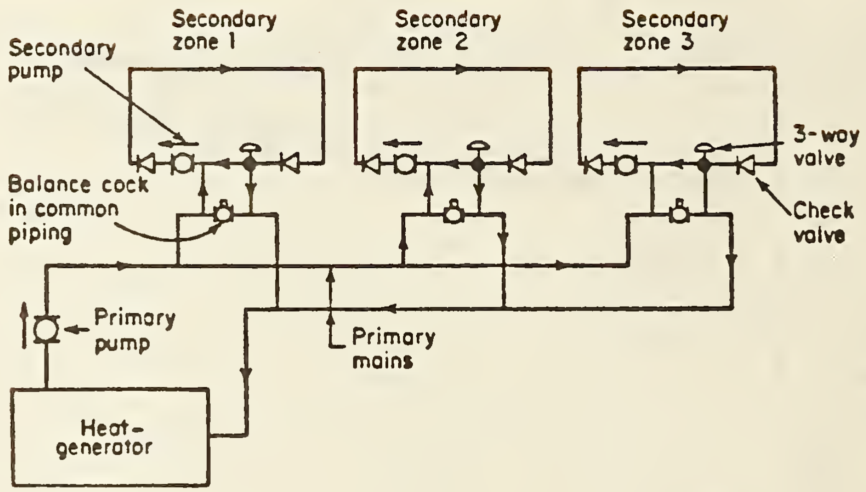

Figure 2.3. Multizone hot water system with primary and secondary pumping

The series loop one-pipe system is commonly used in the smaller buildings and in subcircuits of larger buildings. The hot water flows successively through the heat emitting devices (usually baseboard or finned-tube units) which serve as part of the circuit. All series heat extraction devices are affected by the control or regulation of the hot water delivery. Parallel installations of the heat extraction units, which permit individual radiator control in a system with a single-pipe main, require a diverting tee that cause a pressure drop between supply and return runouts, thereby causing circulation through the unit. Two-pipe systems are used as mains in larger installations, where the subcircuits and/or zones may be either one-pipe or two-pipe systems.

Air must be eliminated from the system to reduce piping corrosion and noise following repairs or retrofits. Venting may be manual or automatic, with the air removal from the piping close to the outlet side of the heat source (furnace, boiler) where the air liberation is maximum. Low pressure systems may have provision for air trapping in the expansion tank by a boiler fitting with a dip-tube or other air-separating devices. Closed expansion tanks are used to allow for the expansion and contraction of the system water with temperature changes and to provide a controlled system pressure above the saturation pressure (except for steam pressurized vessels maintained at the saturation pressure).

Insulation of steam and hot water heating pipes with factory applied "jackets", where the seams were sealed by adhesive materials, has been common practice. In older buildings the deteriorated conditions of original insulation may require replacement. Selection of replacement insulation materials should be made consistent with the recommendations and criteria discussed in [2]. Boiler, furnace insulation, and hot water storage tanks have had cementatious materials (portland and asbestos cement) applied to the outer shells. Package (scotch marine) boilers usually are furnished by the manufacturers with insulation covered by a metal jacket. <u>Local requirements regulating handling and removal of asbestos containing materials, and personnel safety/health procedures during retrofit/renovations or upgrading must be followed</u>. Substitute materials used to repair (patch) or replace thermal insulation materials subjected to the conditions on and about combustion type heat generators should be selected following referenced criteria in [2]. Warm air furnaces typically have metal jacket exteriors with thermal insulation applied to the inside surfaces by the manufacturer (additional external or internal insulation benefits requires more information to be developed).

Unitary space conditioning systems have increased in usage largely due to requirements for individual energy metering. Such equipment or appliance installations are similar to those in single-family dwellings, in some cases with modifications for mounting locations for installation (e.g., through the wall, in mechanical equipment rooms, enclosure in soffits or dropped ceilings). The requirements for such individual residential equipment are discussed in [3].

2.1.3 Domestic Hot Water Systems

The domestic hot water intended for residential, institutional, and commercial building service, (other than for space heating) is supplied by a water heater. The equipment, sometimes called a "domestic hot water boiler " indicates a once-through unit as distinguished from a recirculating hot water boiler for space heating. For domestic hot water service systems in large buildings, the reheat of hot water by recirculating piping systems is a common practice. The equipment, ratings, fuel type, method of heat addition (directly or indirectly fired), types of controls and lining materials are usually indicated by the manufacturer's tag plate on the devices. Insulated storage tanks are normally provided for hot water reserve; otherwise unusually large heaters would be required for the peak demand period. Instantaneous (also known as tankless or continuous) water heaters which supply hot water for immediate use (without a storage tank) are designed to meet maximum temperature demands at peak draw. Sizing procedures for instantaneous, semi-instantaneous, and indirect water heating equipment and boilers in buildings, with the methods for determining total demand are discussed elsewhere [5, 7]. Pipes and fittings for domestic hot water should be insulated to conserve the energy used to heat the water and to provide the design capacity at required temperature at the point of use. Small storage tanks and heaters are mostly manufactured with integral insulation. On non-insulated heaters/storage tanks insulative coverings should be provided. Several types of building installations are shown in figures 2.4, 2.5, 2.6 (from [8]).

Water heaters are classified as direct fired when the heat is transferred to the water from combustion gases or by an electric contact heater through heating surfaces (coils, tubes, or shell) and indirect fired when the thermal energy is absorbed and transmitted from a secondary source (steam or hot water). The direct fired water heater is completely independent of the building heating system. Storage tanks are usually installed to handle peak load demands with both types of heat sources. The storage water heater combines the equipment functions for heat transfer (direct or indirect) with the volumetric capacity of the storage tank. Such configurations do not place a large instantaneous demand on the fuel source, and in the case of indirect heating limits the withdrawal of steam generated in a boiler.

For older buildings many "non-code" water heaters were manufactured, especially for domestic use [9]. Those included the range boiler (with side-arm heater) and the bucket-a-day heater. The range boiler (essentially a storage tank) was manufactured in accordance with "Simplified Practice Recommendations for Ferrous Range Boilers, Expansion Tanks, and Solar Tanks," U.S. Department of Commerce Standard R8-50.

As in current practice, casualty insurance carriers and State Board of Boiler Rules and Regulations generally required hot water heaters to be constructed in accordance with the ASME* Boiler and Pressure Vessel Code, Section IV -- Low

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* See abbreviations listing in appendix. Updated codes and standards may replace the older equipment standards.

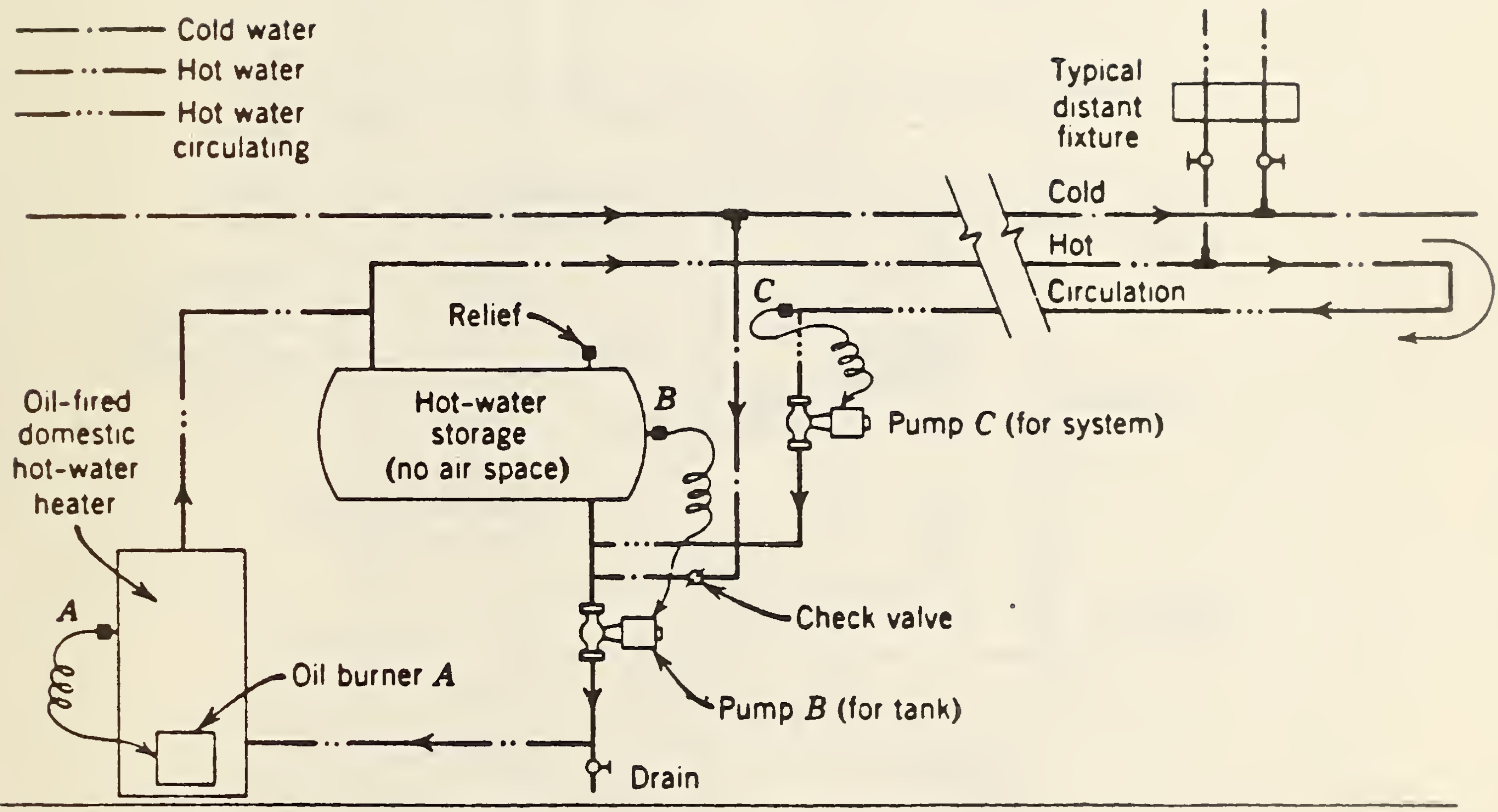

Figure 2.4. Forced circulation of domestic hot water especially needed in long, low buildings

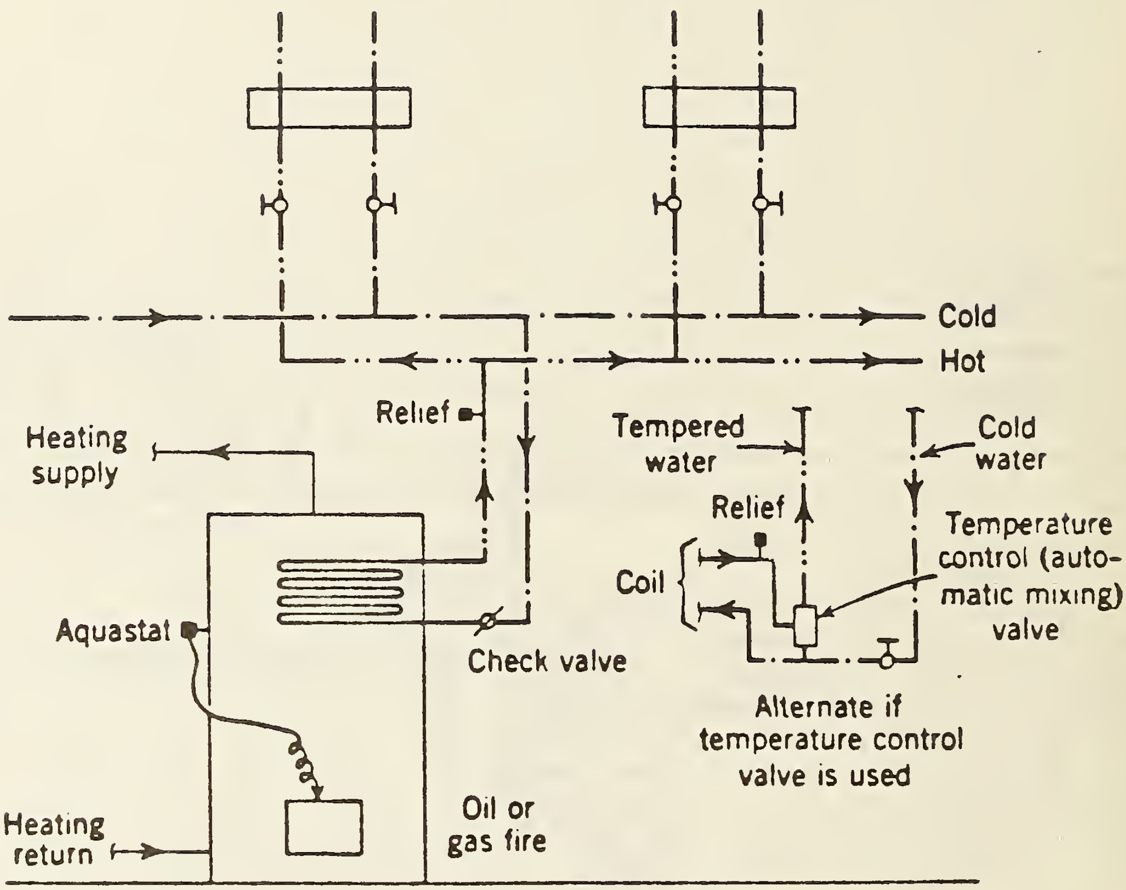

Figure 2.5. Domestic hot water from a built-in tankless coil in a hot water heating boiler. This method, suitable for small, compact installations, provides no circulation.

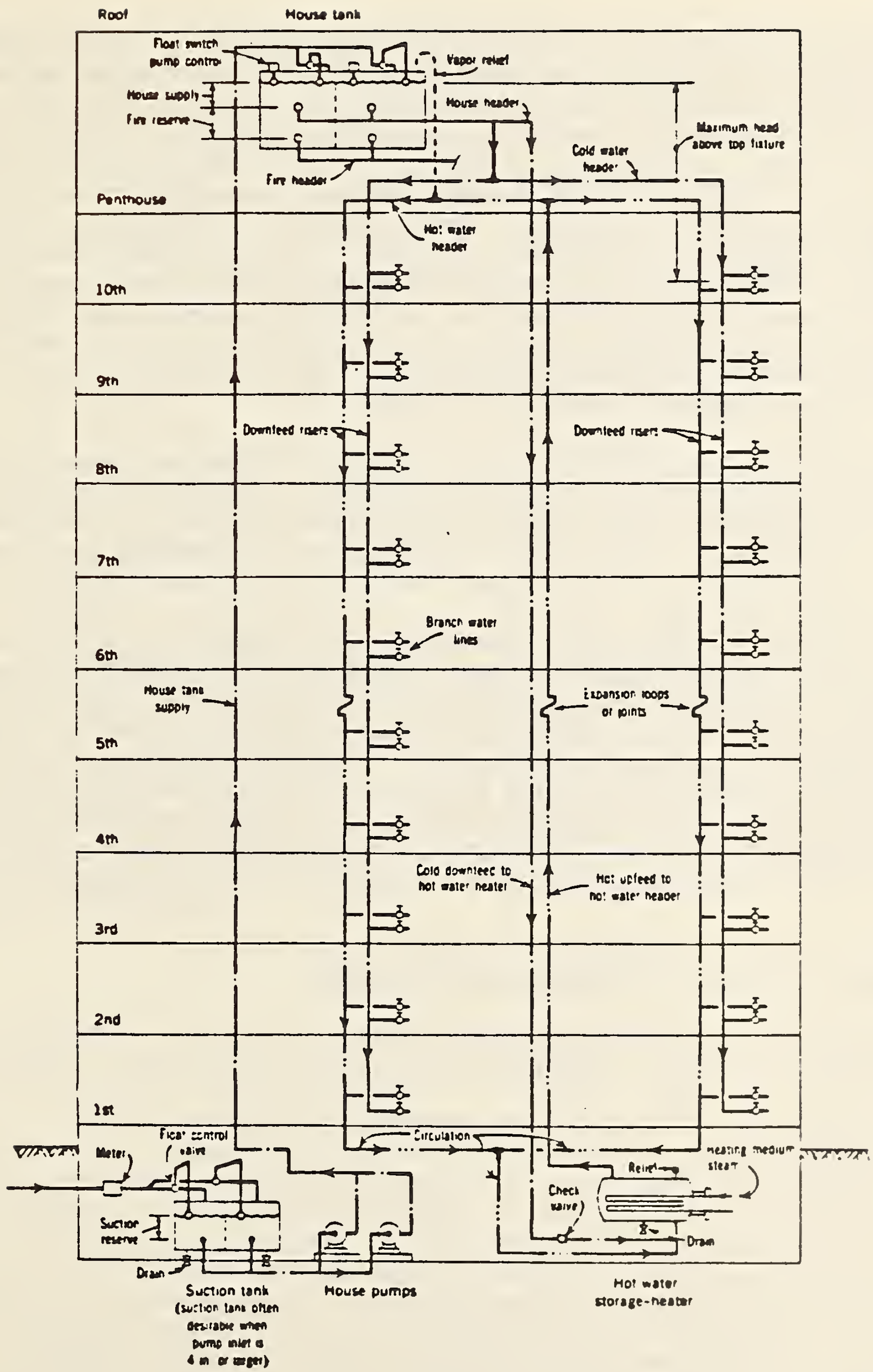

Figure 2.6 Downfeed water distribution. Schematic section, part of the water services of a 10 story building. Hot water circulation is through the hot upfeed, in two directions at the hot water heater and down to the tank through the two downfeed hot water risers.

Pressure Heating Boilers (up to 160 psig pressure or 250°F); unfired storage tanks constructed in accordance with Section VIII — Unfired Pressure Vessels. Electric water heaters were constructed, tested, and rated in accordance with National Electrical Manufacturing Association (NEMA) Standard 45-105 -- Electric Water Heaters; storage electric water heaters followed NEMA Standard C72.1 -- Household Automatic Electric Storage Water Heaters. Gas-fired water heaters required tests and ratings for quality of construction and compliance with American Gas Association (AGA) Standard Z21.10, "Approval Requirements for Gas Water Heaters." Indirect storage and tankless water heaters were tested and rated for compliance using test procedures and rating codes of the Institute of Boiler and Radiator Manufacturers (now superseded by the Hydronics Institute) in tests conducted by independent laboratories. Current versions of the requirements should be reviewed for retrofit actions.

Additional information concerning the various types of water heaters can be found in [9] as well as in other building equipment handbooks. Oil-burning, gas-burning, and electric energy source heaters are described in manufacturer specification brochures. Burners for replacement are available, over ranges of design heat release rates, from equipment manufacturers. Replacement burners must be selected within the furnace or boiler rating limits. Internal flues and hot gas paths are designed to accommodate the combustion products over the heat exchanger gas side surfaces for ranges of prescribed pressure drops to transfer heat to the water. Modifications of the hot gas flow paths, e.g., with turbulators to raise heat transfer rates, or derating of boiler systems, should be done under professional direction. Retrofit replacement burners should be selected in accordance with manufacturer specifications within the range of heat release limits originally provided. In retrofitting the hot water system, compatible burner and draft controls for automated operation with computerized energy management systems or individual manual operations must be selected.

2.2 FUNCTIONS OF BOILERS, FURNACES, WATER HEATERS

The primary function of the heat generator (heat source) is to provide a means for transferring the heat of combustion of a fuel (or electrical resistance heat) to the water or steam. The rate of consumption of input fuel is controlled by the type of fuel burning equipment, firing method for the types of fuels and the capacity of the burners, or grate size with solid fuels. Combustion chambers for some types of burners provide for containment of the flames. The heat release rate and the maximum temperatures (accounting for radiation) attained impose requirements on the construction. Excessive temperatures and particulates from the combustion process may cause erosion of refractory materials and heat exchange surfaces. Depositions on heat exchange surfaces (walls and tubes) can limit the effectiveness of the thermal energy transfer; outer tube surface accumulations of soot (or other deposits) and internal tube wall surface depositions (from minerals precipitated from the water flow and other sludge precipitates) requires systematic inspection and maintenance procedures to maintain the design performance levels. Increased chimney gas temperatures will result from poor heat transfer and are an indicator of reduced thermal efficiency. Surface heat absorption problems are reduced through proper maintenance and operation procedures. Waterside surfaces coated with scale, precipitates, and other sludge will tend to overheat and burn out. Fireside surfaces are subject to deterioration from corrosion and erosion, caustic embrittlement of materials, frequency (amount and rate) of temperature changes in heating and cooling cycles, and expansion and contraction.

Combustion requires sufficient air for burning the fuel (ideally, the chemical reaction goes to completion and the oxygen is consumed, i.e., the stoichiometric condition). The flow of air and combustion products is caused by buoyancy of the hot gases and the resulting pressure difference between the burner inlet and the exhaust stack (chimney or flue). The driving draft can be induced by the chimney effect (natural draft) or by mechanical means (blowers or power burners). Beyond the theoretically predicted combustion air requirement, excess air is necessary to supply additional oxygen for completion of fuel combustion in regions where poor fuel/air mixing occurs (e.g., long grates with solid fuels). The quantity of excess air significantly influences the boiler or furnance temperature and the overall thermal efficiency. In very large systems preheating of combustion air and feedwater with waste heat recovery has been utilized to improve overall thermal efficiency (frequently identified as economizers).

The temperature of the combustion gases entering the flue gas stack is limited by the dewpoint; condensation of water vapor may occur when the exit temperatures are too low. Condensation conditions must be avoided to prevent corrosion particularly with fuels of high sulfur content. Heat recovery devices for extraction of the latent heat from the water vapor in the combustion products (e.g., condensing furnace) require materials that are capable of withstanding the severe conditions. The discharge temperatures of the exhaust gases from condensing furnaces are sufficiently low (further air dilution may be unnecessary) that a flue vent discharge through a side wall, instead of a chimney, may be installed.

3. MECHANICAL RETROFITTING CRITERIA FOR MULTIFAMILY BUILDINGS

Mechanical equipment and product requirements for eligible options in the DoE Weatherization Assistance Program for large buildings were reviewed. The performance requirements, maintenance, operation, and control of mechanical equipment and devices in multifamily building central systems for space conditioning and domestic hot water service were of primary concern. Generally, such equipment is required to meet more detailed specifications and installation practices which differ from those for individual residential buildings. Controls, thermostatic regulators, energy, and duty cycle systems which can generally be integrated with an automated (programmable) central management system were included for large buildings since effective energy saving benefits can be obtained. The concerns for the higher residential density are reflected in many jurisdictions by regulations for multifamily buildings which require building permits, licensed installers and inspection/approval procedures as well as adaptions to model codes that are specific to local conditions. The criteria for eligible options applicable to both single-family dwellings and multistory buildings include retrofit installations of thermal insulation, caulking materials, sealants, windows, doors, and individual apartment utility equipment (e.g., hot water appliances or devices and tanks, furnaces) as described by Rossiter [1, 2] and Kweller [3].

The criteria for performance, fire and health safety, and structural integrity are usually prescribed for large buildings through local legal requirements with reference to model codes. Product compliance, installation, and maintenance practices with inspector approvals are established in most local jurisdictions through the legislative process (see illustrative listing examples in appendix B). In many jurisdictions a requirement for upgrading the <u>entire</u> mechanical system installation may exist if any subset of the existing equipment and devices is upgraded. <u>It is essential that local groups conducting energy upgrading establish the needs for compliance or exceptions in the locality. For all items which meet the recommended acceptable DoE criteria their use is allowed only if they do not violate applicable local building-related codes or variance approvals (exceptions) are in conformance with local regulations.</u> Repairs, tuneups, and installations by licensed (or certified) service staff may also be required.

Asbestos thermal insulation, often in combination with other cementatious materials, was commonly applied to furnaces, boilers, storage tanks, and piping in older installations. The recent concerns from investigations of potential hazards of asbestos have resulted in local regulations for removal and handling. In conducting energy retrofits <u>it is essential that local requirements for handling or removal of asbestos materials be followed.</u>

The expanded DoE Weatherization Assistance Program is intended to conserve energy by including repair, component replacement (e.g., burners), and retrofit of the installed mechanical equipment in multifamily buildings. The selection and guidance for establishment of the recommended retrofit options was derived from review of the literature specifically oriented to multifamily building applications. Equipment and device standards and specifications were surveyed for suitability as a basis of the criteria. Those included certification programs by appropriate organizations and listing procedures to show compliance with standards, (where such exist). The equipment and products considered eligible for the DoE WAP and the criteria for determining their eligibility are summarized in table 3.1. In cases where no applicable standards exist, specifications established by reputable manufacturers and/or associations or adequate experience to confirm the performance effectiveness of the retrofit elements or procedures should be acceptable. The use of those items should not be hindered by requiring that new standards or specifications be written.

The list in table 3.1 contains reference to the primary measures that may be considered for implementation in weatherization projects. A comprehensive tabulation of many other potentially useful requirements, practices, methods, standards, and many sponsoring organizations are provided in chapter 45 of the 1983 ASHRAE Equipment Handbook. Methods for evaluation of high-rise residential buildings for determination of actual energy usage may be found in many publications and recent textbooks. ASHRAE Standard 100.2P, "Energy Conservation in Existing High-Rise Buildings," provides information and stated requirements for retrofits, changes, additions, strategies, and maintenance procedures to conserve energy.

The local jurisdictional requirements which regulate the acceptable practices and installations are usually established by the mechanical, plumbing, and building codes. In such documents, reference to or listing of standards will be found which guides the approval authority. Beyond listed or referenced standards the local building official may frequently provide approvals for equipment and/or practices through submittal of necessary information, data, and other necessary documentation, as part of provisions for exceptions and variances.

The Laboratories Certification Seal of the American Gas Association Laboratories indicates compliance with applicable National standards for appliances and accessories. Those are applicable for use only with the classes of fuel gases and input ratings and the installation conditions described. The information is usually provided by manufacturer's bulletins, specifications, and brochures. Compliance with National standards for equipment and other fuel types can generally be obtained from equipment specifications and information published by the manufacturers. The assistance of the National Oil Jobbers Council may be obtained from their association representation for the oil-fired equipment manufacturers. Other organizations that either conduct certification programs or review performance test data to evaluate and provide approvals are listed in section 3.1. The listing in table 3.1 also contains the title of referenced standards indicated by letter and number designations .

Caution should be exercised in the examination of identification tags, specification plates or printed brochures for laboratory certification, or approval symbols. For example, electrical components, motors, wiring, and switch/relay components are usually listed by Underwriters Laboratories (U.L.) when U.L. standards (or others, such as ANSI, ASTM, etc.) are met. The display of the U.L. symbol may be applicable to only the electrical components and not the entire device (where in some cases, such as for controls, standards have not yet been developed). In other cases the approval listing indicates that

Table-3.1 Summary of Recommended Criteria[1]

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
	Heat Exchangers
Heat Exchangers	ASME Pressure Code provisions, as applicable to pressure levels.
	Commercially available.
	Standards of Tubular Exchanger Manufacturers Association (last edition with 1983 Addenda, TEMA).
With Gas-Fired Appliances*	AGA Requirement 70-1 for Gas-Fueled Equipment.
	ANSI Z-21 (standards, as appropriate, of committee for domestic and commercial types of equipment).
	AGA Laboratories Certification Seal.[2]

* The heat reclaimer is for installation in a section of the vent connector from appliances equipped with draft hoods or appliances equipped with powered burners or induced draft and not equipped with a draft hood.

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
	Thermostat and Control Systems
Automatic Setback Thermostats	Listed by Underwriters Laboratories (U.L. symbol).
	Conformance to NEMA DC 15-1979.
Line Voltage or Low Voltage Room Thermostats	NEMA DC 3-1978.
Automatic Gas Ignition Systems	Conformance to ANSI Z21.21.
	AGA Laboratories Certification.[2]
Energy Management Systems	Listed by Underwriters Laboratories (U.L. symbol).
	Commercial Availability.
Hydronic Boiler Control	Commercial Availability.
Microcomputer Burner Control	Commercial Availability.

[1] All items are to be installed in accordance with manufacturers recommendations and/or as required in existing and applicable building and mechanical-related code. Revisions of specifications and updated standards should be reviewed for applications in Weatherization Assistance Programs. Whenever determined, latest revisions should be included where applicable.

[2] See description and discussion of AGA Certified Appliances and Accessories.

Table 3.1 Summary of Recommended Criteria (Continued)

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
Water Heater Modifications	
Insulate Tank and Distribution Piping	(See Insulation Standards [2])
Install Heat Traps on Inlet and Outlet Piping	Applicable Local Plumbing Code.
Hot Water Pipe Heater Strips	Listed by Underwriters Laboratories (U.L. symbol).
Reduce Thermostat Settings	State or Local Recommendations.
Install Stack Damper, Gas-Fueled	ANSI Z21.68, ANSI Z21.67, including addendas A and B, ANSI Z223.1-1980.
Install Stack Damper, Oil-Fueled	UL-17, NFPA 31-1983[3],
Waste Heat Recovery Devices	
Desuperheater/Water Heaters	Conformance to ARI 470-80[4]. Conformance to ARI 1060-80.
Condensing Heat Exchangers	Commercially available components and in new heating furnace systems to manufacturer specifications.
Condensing Heat Exchangers (Commercial, Multistory Building, and Institutional)	Commercially available with teflon lined tubes to manufacturer specifications.
Energy Recovery Equipment	Energy Recovery Equipment and Systems Air-to-Air (1978) Sheet Metal and Air Conditioning Contractor's National Association (SMACNA).

[3] NFPA indicates National Fire Protection Association.

[4] ARI indicates Air Conditioning and Refrigeration Institute.

Table 3.1 Summary of Recommended Criteria (Continued)

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
Boiler and Furnace Repairs and Modifications/Efficiency Improvements	
Installation of Gas Conversion Power Burners (for Gas- or Oil-Fired Systems Replacements)	In conformance with, or latest, ANSI Z21.8a, ANSI Z21.17 and Installation ANSI Z223.1-1980 (or latest National Fuel Gas Code). AGA Laboratories Certification Seal.
Replacement Oil Burner	ANSI Z96.2 (UL 296). ANSI Z91.2. NFPA 31-1983.
Power Burners (Oil/Gas)	Conformance to ANSI Z223.1, National Fuel Gas Code; ANSI Z83.1 Gas Installations; NFPA 31 Oil Equipment.
Furnaces, Oil	Installation of Oil-Burning Equipment, NFPA 31-1976.
Furnaces, Gas	Gas-Fired Central Furnaces, ANSI Z21.47-1978.
Readjustment Boiler Water Temperature or Installation of Automatic Boiler Temperature Reset Control	ANSI/ASME CSD.1-1982, and applicable section of ANSI Z223.1-1980 and NFPA 31-1983.
Boilers	Boiler and Pressure Vessel Code (eleven sections) ASME 1980 or latest. Testing and Ratings Hydronics Institute (HYDI).
Clean Heat Exchangers, Adjust Burner Air Shutter(s), Check Smoke No. on Oil-Fueled Equipment. Check Operation of Pump(s) and Replace Filters	Per Manufacturer's Instructions.
Combustion Chambers	Refractory linings may be required for conversions.
Heat Exchangers, Tubes	Protection from flame contact with conversion burners by refractory shield.
Thermostatic Radiator Valves	Commercially available. One-pipe steam systems require steam air vents on each radiator, see manufacturer requirements.
Boiler Duty Cycle Control System	Commercially available. National Electrical Code (NEC) and local electrical codes provisions for wiring.

Table 3.1 Summary of Recommended Criteria (Continued)

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
Heating and Cooling System Repairs and Tuneups/Efficiency Improvements	
Burners	See power burners, gas, oil.
Training and/or Experience	Comparable to courses of Boiler Efficiency Institute, World Energy Engineering Congress Seminars, Trade schools or equipment manufacturer's courses. Local jurisdictional licensing and practitioner requirements may be prescribed.
Duct Insulation	In accordance with FS HH-1-558B (See [3] Insulation Sections). Training and experience.
Reduced Input of Burner, Derating--Gas-Fueled*	In accordance with local utility company procedures, if applicable, for gas-fueled furnaces and Appendix H of NFPA 54 ANSI Z223.1.
Oil-Fired	In accordance with NFPA 31-1983, Standard for the Installation of Oil-Burning Equipment.
Replacement Combustion Chamber, in Oil-Fired Furnace, Boiler	In accordance with NFPA 31-1983.
Clean Heat Exchanger and Adjust Burner: Adjust Air Shutter and Check CO_2 and Stack Temperature; Clean or Replace Air Filter on Forced Air Furnace	See ANSI Z223.1, Appendix H.
Gas-Fueled Heating Systems, Vent Dampers	In accordance with applicable sections, National Fuel Gas Code Z223.1 including Appendices H, I, J, and K. ANSI Z21.66-1977 and Addenda A and B for Electrically Operated Dampers. ANSI Z21.68-1978 and Appendices A and B for Thermally Activated Vent Dampers. ANSI Z21.67-1978 and Appendices A and B for mechanically actuated vent dampers.

* This may be prohibited by local jurisdiction -- it may also void the manufacturer's warranty. The National Fuel Gas Code does not specifically endorse this.

Table 3.1 Summary of Recommended Criteria (Continued)

Equipment or Product	Recommended Criteria--Reference Standard, Specification, Practice
Oil-Fueled Systems, Vent Dampers	In accordance with applicable sections of NFPA 31-1983 for installation and in conformance with UL 17.
Reduce Excess Dilution Air:	
a) Reduction of Vent Connector Size of Gas-Fueled Appliances	See Part 9 of ANSI Z223.1-1980 and Appendices G and H.
b) Adjustment of Barometric Draft Regulator for Oil-Fuels	NFPA 31-1980 for Air Fueled and per manufacturer's (furnace or burner) instructions.
Replacement of constant burning pilot with electric ignition device on gas-fueled furnaces or boilers	ANSI Z21.71-1981.
Readjustment of Fan Switch on Forced Air Gas- or Oil-Fueled Furnaces[1]	In accordance with applicable sections; ANSI Z223.1-1980. Appendix H for Gas Furnaces and NFPA 31-1983 for Oil Furnaces.
Forced Air Systems:	
Duct Furnaces (Gas)	ANSI Z223.1-1980, National Fuel Gas Code.
Heat Pumps	Listed by Underwriters Laboratories (U.L.), ANSI/UL 559-1976.
Outlets, Inlets, Air Flow[7]	Methods of Testing for Rating the Air Flow of Performance of Outlets and Inlets, ASHRAE 70-72.
Warm Air Heating Ducts[7]	Installation of Warm Air Heating and Air Conditioning Systems, NFPA 90B.
Air Ducts and Connectors	Factory Made Air Ducts and Connectors (1981), UL 181.

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6 Applies also to forced air systems category.

7 Follow practices as a guideline for existing building installations.

the product performance tests have been performed (and determined to be) in accordance with the pertinent standard(s).

In the retrofit of older boilers and furnaces it is advisable to refer to the manufacturer for rating data. A list of references (from [9]) is reproduced in appendix C that provides information for determining the ratings of older boilers and furnaces. With power conversion burners and reduced excess air (and with changes of fuels) increased heat release, higher temperatures, and greater flame lengths can occur as part of the process to improve thermal efficiency. Selection of burners to assure equipment compatibility is necessary in order to prevent rapid deterioration of combustion chambers, refractory lining materials, and heat transfer tubes. Flame baffles of refractory materials may be necessary to protect against flame impingement on other components. The requirement for limiting retrofits to rated capacity permits the maximum extraction of the usable energy (from the combustion products and/or radiation) that should result in: (a) flue gas temperatures which are within the upper temperature limits of chimney materials, and (b) prevention of condensation at the lower temperature limits (leading to rapid materials deterioration) except for heat exchangers specially designed for condensing-latent heat extraction.

Power conversion burners sold by manufacturers are usually supplied as complete fuel burning systems. Units are generally factory tested, assembled, and wired with the control panel as an integral part of the unit. The burner and forced draft blower sizes will be listed according to the heat release rates (for gas) and consumption rates (for oil) which are offered with insurance approvals appropriate to the size. The packaged units provide simplified installation for most types of boilers by bolting to the front of the boiler. Firing-burner head designs for mixing results in short, clean flames, complete combustion, and fuel savings (according to manufacturer's brochures). The need for specially shaped refractory combustion chambers is claimed to be unnecessary to assist or obtain efficient combustion in newer boilers.

For fuel conversion or burner replacement, burner mounting can be made through the fire door of older boilers at a safe distance below the crown sheet. Such installation is intended to permit greater heat transfer. In older boiler systems (grate fuel retainers) the base or ash pit or chamber area can be filled with sand or refractory rubble with oil- or gas-fueled burners. The effects of complete combustion with well-regulated flame patterns (as compared with older less efficient and high excess air burners) must be considered since higher gas temperatures can lead to thermal stresses and flame impingement on cold surfaces that can deteriorate equipment or cause failures.

Specific examples of energy savings from retrofit options in multifamily buildings generally result from site specific combinations of measures. Average annual energy savings of 39 percent for eight buildings due to the combined weatherization measures (boiler changes, thermal insulation improvement, thermostatic radiator valve installation, etc.), were reported [10] and are discussed in section 4. Only one retrofit measure, the installation of energy efficient modular pulsed combustion gas-air boilers, was made; those replaced a central powerhouse boiler room and underground pumped hot water piping distribution system for heating in a complex of 19 buildings.

Priorities for selection of available options in residential single-family or small buildings have been developed from predictive models and field experience [13-20], some without complete validation. The capability of determining an ordered set of priorities for weatherization actions for multifamily buildings has not been developed (relations among the parameters may be site dependent). The lack of available evaluations and assessments with predictive models to correlate actual energy savings from various combinations of measures and strategies for existing multistory commercial buildings (which have analogies with multistory residential buildings) was shown in [12]. The results reported for large buildings had demonstrated energy savings up to 45 percent but there was no correlation between predicted and actual energy savings. Advantages from mechanical system retrofits for the heating systems in residential homes (only) were calculated to show that those steps provide the most significant cost/benefit options [12]. For retrofits in some steam heated multifamily buildings, the actual modifications to the mechanical system were also indicated to provide more energy savings than other possible building weatherization techniques [10], even though combinations of installed retrofits were actually made. The proceudres that were implemented in examples of mechanical systems retrofits, modifications, and intallation practices are discussed in section 4.

3.1 STANDARDS AND ORGANIZATIONS

The titles of standards listed in table 3.1 and several other useful references are presented below. The organizations which sponsor standards, and their publications that may be sources of information, are provided.

1. ADC - Air Diffusion Council
   435 North Michigan Avenue
   Chcago, Illinois 60611

   - ADC 1062 R4 (1977) - Certification, Rating, and Test Manual

2. AGA - America Gas Association
   1515 Wilson Boulevard
   Arlington, Virginia 22209

   - AGA 80-1 - AGA Requirements for Heat Reclaimer Devices for Use with Gas-Fired Appliances, June 1, 1980.

3. ANSI - American National Standards Institute, Inc.
   1430 Broadway
   New York, New York 10018

   - ANSI/AGA Z21.8-79 - Installation of Domestic Gas Conversion Burners.

   - ANSI/AGA Z21.17b-74 - Domestic Gas Conversion Burners (Addendas A&B)

   - ANSI Z21.21-74 - Automatic Valves for Gas Appliances (Addendas A&B)

- ANSI Z21.47-83 - Gas-Fired Central Furnaces (Except Direct Vent and Separated Combustion System Central Furnaces)

- ANSI/AGA Z21.66-77 - Electrically Operated Automatic Vent Damper Devices for Use with Gas-Fired Appliances (Addenda A and B)

- ANSI/AGA Z21.67-78 - Mechanically Actuated Automatic Vent Damper Devices for Use with Gas-Fired Appliances (Addenda A and B)

- ANSI/AGA Z21.68-78 - Thermally Actuated Automatic Vent Damper Devices for Use with Gas-Fired Appliances (Addenda A and B)

- ANSI/AGA Z21.71-81 - Automatic Intermittent Pilot Ignition Systems for Field Installation

- ANSI Z91.2-76 - Performance Requirements for Automatic Pressure Atomizing Oil Burners of the Mechanical Draft Type

- ANSI/NFPA Z223.1-80 - National Fuel Gas Code

- ANSI/UL 559 - Heat Pumps; February 8, 1983

4. ARI - Air Conditioning and Refrigeration Institute
1815 North Fort Myer Drive
Arlington, Virginia 22209

Conducts equipment performance certification program.

- ARI 470-80 - Standard for Desuperheater/Water Heaters

- ARI 1060-80 - Standard for Air-to-Air Heat Recovery Equipment

- ARI Rating Certification Program

5. ASHRAE - The American Society of Heating,
Refrigerating, and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, N.E.
Atlanta, Georgia 30329

- ASHRAE 70-72 - Method of Testing for Rating the Air Flow Performance of Outlets and Inlets

- ASHRAE 100.2 - Energy Conservation in Existing Buildings High-Rise Residential

- ASHRAE 103-1982 (ANSI) - Method of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers

6. ASME - American Society of Mechanical Engineers
345 East 47th Street
New York, New York 10017

- ASME CSD.1-82 - Controls and Safety Devices for Automatically Fired Boilers

- ASME 1980 Boiler Pressure Vessel Code (selected sections)

7. EPA - Environmental Protection Agency
   EPA Office of Research and Development
   Industrial Environmental Research Laboratory
   Research Triangle Park, North Carolia 27711

   - EPA 600/Z-75-069-9 - Guidelines for Residential Oil Burner Adjustments

8. GAMA - Gas Appliance Manufacturers Association, Inc.
   1901 North Fort Myer Drive
   Arlington, Virginia 22209

Conducts furnace and boiler efficiency certification program.

9. HYDI - The Hydronics Institute
   35 Russo Place
   Berkeley Heights, New Jersey 07922

Formerly: National Boiler and Radiator Manufacturers Association and Institute of Boilers and Radiators.

Conducts cast iron and steel boilers finned-tube radiation, baseboard radiation testing program for rating and use of I = B = R and SBI approval emblems.

10. NEMA - National Electrical Manufacturers Association
    2101 L Street N.W.
    Washington, DC 20037

    - NEMA DC 3-1978 - Low-Voltage Room Thermostats

    - NEMA DC 15-1979 - Line-Voltage Room Thermostats

11. NFPA - National Fire Protection Association, Inc.
    Batterymarch Park
    Quincy, Massachusetts 02269

    - NFPA 31 - Installation of Oil-Burning Equipment 1983

    - ANSI/NFPA 70 - National Electrical Code (NEC)

    - NFPA 90B - Standard for the Installation of Warm Air Heating and Air Conditioning Systems 1980

12. SMACNA - Sheet Metal and Air Conditioning Contractor's National Association
    P.O. Box 70
    Merrifield, Virginia 22116

    - SMACNA 1978 Energy Recovery Equipment and Systems Air-to-Air

- SMACNA 1974-3 Thermoplastic Duct (PVC) Construction Manual

13. TEMA - Tubular Exchanger Manufacturers Association
    331 Madison Avenue
    New York, New York 10017

    - TEMA (1983 Addenda) Standards of Tubular Exchanger Manufacturers Association

14. UL - Underwriters Laboratories Inc.
    333 Pfingsten Road
    Northbrook, Illinois 60062

    - UL 17 - Vent or Chimney Connector Dampers for Oil-Fired Appliances

    - UL 181 - Factory Made Air Ducts and Connectors; September 16, 1981

    - UL 296-80 - Oil Burners; December 3, 1982

3.1.1 Equipment Efficiency Improvements

Improvements in thermal efficiency of boilers and furnaces can be obtained through retrofitting, replacement of burners, installation of control devices, and also by performing systematic tuneups and maintenance procedures. Many of the techniques can be applied to existing units, but consideration should be given to the structural integrity, status, and lifetime expectancy; further evaluations may indicate that it is more economical to install a modern, efficient new unit (that may particularly apply when extensive furnace/boiler derating is required). The methods described here are intended to provide only brief descriptions. Specific information based upon manuals, training or experience, and recommended installation practices for materials and products should be consulted. Conformance with local jurisdictional building requirements may be necessary and gas emissions regulations may require tests for conformance to air quality requirements. Instruction materials consolidated from several sources of information [22] are presented, with brief descriptions of technical modifications and practices (e.g., adjustment of fuel/air ratio, heat recovery devices, and combustion controls) that can be applied in multifamily buildings. Other sources of information on advanced methods (under investigation) for improvements that may be applicable in the WAP are discussed in [23, 24, 25]. Examples of modifications that can be made are provided in the following:

Turbulators

Firetube turbulators are baffles inserted in tube bundles that project into the combustion gas flow paths to induce turbulence in the hot gas stream in order to increase the heat transfer to the tube surfaces. The increased gain of energy in the water or steam increases the thermal efficiency which results in reduced exhaust gas (chimney) temperature over a range of firing rates. The application is frequently made with reductions in the excess air levels of the burner/draft air. Installation of turbulators alters the combustion gas flow resistance so that they can also be utilized to balance or redistribute the hot gas flow. Readjustment of burner controls following installation of turbulators may be necessary, particularly when reductions of excess air are also accomplished. Such adjustments can be determined by a post installation efficiency check (for stack temperatures, measurements of O_2 and CO_2) which should be performed to verify the degree of complete combustion.

Combustion Systems Control and Instrumentation

The quantity of fuel and air flows, duty cycles, setback or nonoperational periods are regulated by elements of the combustion control system and/or energy management systems. The combustion control arrangement can range from manual control to advanced computerized methods. Instrumentation provisions consist of sensing elements that provide the current conditions of operation and performance. The determination of the difference between the desired set point and the measured signal provides output for control action to adjust the operating levels. To detect deviations automatically from desired operation unless an interface with an energy management system is required. Input signals are supplied to operator displays, or with automated systems, for corrective actions. Increased concerns for environmental pollution control may require special instrumentation for monitoring stack emissions of gaseous pollutants.

Oil and Gas Burners and Supply Systems

Oil and gas burner retrofit actions have a range of options for upgrading. These actions vary from relatively simple maintenance cleaning and tuneups, orifice replacements or installation replacements with new conversion power burners. Reduction of the excess air levels while maintaining complete combustion with increases the thermal efficiency. The new combustion systems have improved fuel atomization and/or air/fuel mixing to achieve extremely low excess air operating levels. In equipment for large building the firing rate variations require capabilities of regulation and modulation ranges for control of off-peak firing rate operation. Appliance type equipment for small buildings may not utilize variable output burners and therefore cannot be modulated. High efficiency pulse combustion burner systems have been developed for appliances and have been applied in weatherization projects as reported in [11, 23].

The changes in flame shape and length, with higher temperature levels from improved combustion can require modifications to the combustion chambers. Refractory, high temperature resistant baffles may be required to prevent impingement of the flame on tubes and interior furnace walls. Pattern changes of interior combustion gas flows that result from internal alterations by burner modifications, turbulators, draft flow reductions, etc., do not appear to have been evaluated. For older installed mechanical equipment the ratings for replacement burners provided in manufacturer specifications should be compatible with the original capacity of the furnace or boiler (or for derating practices with lower heat release rates).

Derating

Reductions of energy losses by energy conservation measures such as increased building thermal insulation, storm windows, reduction of air infiltration, and piping insulation, result in decreased thermal energy demand loads. When changes with sufficiently large energy savings occur, the rated capacity of the existing system may be substantially beyond that required. Selection of smaller burners, changes of hot water or steam flow rates, and modifications of controlled duty cycle load management procedures can be optional procedures for reduction of the thermal energy output requirements from the source, so-called derating techniques. Fuel savings and higher annual energy performance efficiency can result from derating of existing installed equipment. Derating results in lowered stack temperatures (which are related to increased thermodynamic efficiency); however, caution must be exercised since there is a concern for material deterioration due to water vapor condensation that can occur in the flue and sufficient draft to transort combustion products must be maintained. The fuel burning periods can often be increased at lowered fuel flow rates thereby decreasing the on-off cycles; in such cases the number of cycles for reheating the thermal mass of the boiler/furnace is reduced and improved dynamic thermal performance efficiency is obtained.

Energy Management Systems and Controls

Energy management systems (EMS) and controls provide effective methods and techniques for energy conservation. Wide ranges of capabilities and features for implementation of strategies are available from commercially available devices with manufacturer descriptions for applications. In commercial buildings the potentials for energy savings through the use of computerized energy management systems have been estimated to vary from 15 to 40 percent [26]. Building automation systems manage the energy use through time and event programming, load cycling, duty operation (burner operation and circulation pumps), boiler optimization (particularly with modular units), and setback (timer) operation, and also perform diagnostic procedures. To interface with control components, signal sensor devices (primarily thermostats, burner/ignition control elements, and water level instruments) are required as inputs to determine and optimize performance levels. Zone controls can be implemented (for separate regions of the building) which provide only the heat required within those parts. Zone controls are applicable only for piping or air flow distribution systems which can be sectioned off for the different building regions. Analysis of the system to determine whether zone control is possible will require services by experienced professionals. The zone controls will probably be less costly than individual room control (e.g., individual radiator controls) according to [27].

Many boiler systems heat water to a fixed temperature, independent of the outdoor temperature. Hydronic heat systems usually set the design discharge water temperature sufficiently high to provide for the coldest outdoor temperature anticipated. Energy waste can occur during milder weather due to overheating. Manufacturer claims for energy savings with outdoor reset controls vary from 15 to 20 percent (which may be based upon the inclusion of unoccupied time periods with shutdowns and use of a timer programmer for setback control).

Resetting boiler water temperature downward usually reduces stack losses, indicating an improved thermal efficiency for a fixed firing rate.

Use of computer energy management control systems requires high reliability, low downtime, and local availability of immediate service with trained support personnel [28]. Much of the building energy savings has been attributed to conventional time clock controlled functions and improved temperature controls [29]. The simplest manual needs for remote stop/start operations to accomplish the clock set functions were indicated to be achievable with only a control panel (with switch/ relay and toggle switch inputs) to attain comparable automated energy savings (reliance on the operator may be a concern). The benefits for control of mechanical equipment through an EMS provides greater flexibility, can improve labor efficiency, reduce maintenance costs, and extend equipment life, although such measures have been less quantifiable [26].

Heat Recovery Devices and Air Preheaters

Heat exchangers of conventional design for waste thermal energy reclamation are available from many manufacturers in shell and tube, multishell, and plate and frame design. Those units installed in process industries, commercial buildings, and large residential buildings provide savings in boiler fuel, reduced steam use, and lowered boiler horsepower consumption. Heat recovery boosts system heating capacity, extends boiler life, and contributes to reductions of gas emissions (which reduces pollutants). Examples of other heat recovery devices are the rotary heat wheel, and heat pipe exchangers (unpowered and no moving parts except for auxiliary dampers). The recovered thermal energy from combustion stack exhaust gases, discharged heated air, and return steam or condensate can be utilized for various purposes. Heat exchange to incoming air for space conditioning results in energy savings through reduced loads on existing space conditioning equipment. Heating of incoming cold water supply for boiler makeup water or domestic hot water service is an energy conservation opportunity.

The lowered temperature impact on gas emission products from the chimney must be considered where air pollution regulations are applicable since concentrations of NO_x, CO may be changed. Moisture condensation on heat transfer surfaces, flues, and chimneys at lowered exhaust stack temperatures could lead to increased corrosive conditions. Materials capable of withstanding such environments are required for the heat recovery equipment. Existing interfaces, ducts/flues and chimneys should be able to tolerate the changed conditions. At sufficiently low gas discharge temperatures, plastic exhaust flues/outlets have been recommended with small appliances which, however, may not be applicable to large building systems due to local fire/safety regulations.

Flue gas recovery systems based upon latent heat extraction from the combustion gas water vapor with condensing heat exchangers are available with packaged furnaces and as an add-on retrofit equipment. The open loop recovery system discharges the condensate into a building plumbing drain. Local jurisdictions may be required to reach a decision on the acceptability of the possibly corrosive discharged water for collection in the plumbing drain piping. Neutralizing the small amount of condensate by running the flow over a limestone block prior to collection in the drain appears to be practical*.

A closed loop system recirculates and sprays water to absorb the heat from the hot exhaust gases. The heated water supplies the recovered thermal energy through a heat exchanger to preheat incoming air or water. Cooled flue gases, which have given up the waste heat, at a sufficiently low temperature can be vented outdoors through a plastic flue pipe (according to the manufacturer's brochure). For existing furnace installations in large buildings, with heat input rates varying between 200,000 to 1,500,000 Btu/hr, and an assumption of 60 percent average efficiency, the provisions for condensing closed loop systems were claimed to have payback from fuel savings in less than 2 years for both oil and gas (based upon a set of required heating condition) with a 30 percent fuel savings**).

A well established function for waste heat recovery is the use of an economizer in large plants, which is an air preheater for transfer of heat energy from the stack exhaust gases to the incoming combustion air supply. The boiler thermal efficiency is improved as a result of the reduced stack gas temperatures. The benefit from combustion air preheating permits the burner to operate with lower excess air level (LEA), an effect similar to that provided with power burner conversions.

3.1.2 Thermostatic Radiator Valves and Steam Traps

The installation of non-electric thermostatic radiator valves (TRV) proves a cost-effective small capital investment heating retrofit for upgrading existing hot water and steam heating systems. The installation of nonelectric thermostatic radiator control valves provides short payback periods.

Individual thermostatic radiator controls for one- and two-pipe radiators, baseboard and heat convector units provide individual room thermostat settings for the amount of heat needed within a living unit. The self-contained thermostatic head is nonpowered. Piping rework for retrofit installation is kept to a minimum. Individual radiator controls come in two types depending on the piping system. The one-pipe system requires steam air vent relief (vacuum relief valves) to the atmosphere on each radiation unit. A radiator thermostatic valve should not be applied within a zone control sector if the boiler is cycled from a zoned thermostat. If the steam system does not have vacuum breakers on the risers they must be installed. The two pipe steam (or hot water) systems require the thermostatic valves to be installed in the supply pipe. Manufacturer equipment specifications should be reviewed for availability

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* Private communication from Brookhaven Laboratory on industrial process heat recovery techniques.

** Heat Extractor Corporation brochure -- a supplier of industrial and residential equipment for flue gas recovery systems.

of an insert which permits upgrading older types of hand valve bodies. The use of an insert eliminates the requirement to remove the old valve body, thereby reducing the cost of installation.

The two-pipe steam system carries the condensate away from the radiator in the return line. In order to prevent the escape of steam through the radiator steam traps are installed at each radiator return connection. The device closes when contacted by steam and causes the steam condensation to take place within the radiator. By means of those airtight devices the steam can be generated and circulated at low temperature and partial vacuum [8]. The steam carrying pipes should be kept free of condensate by installation of thermostatic steam traps at the base of all risers, the lead ends of the steam mains, and at low points in the steam distribution systems.

3.1.3 Hot Water Piping and Recirculation Systems

In buildings with hot water circulating systems the design provides for instantaneous delivery of hot water supply with circulating pumps -- the horsepower required is dependent upon the height of the building and the piping distribution system parameters (fitting losses, pipe wall roughness, corrosion on inner pipe surfaces, etc.). Heat losses in long exposed hot water pipes can be reduced with pipe thermal insulation or eliminated by providing strip heaters on the pipes.

Development of a self-regulating, semiconductive polymer material as the core of an electrically powered strip heater has provided new capabilities. The functions of sensing and responding to the localized temperature status, providing heat proportional to the local requirement (control) of electric current along the electrical conductive paths) and on-off switch control have been established based upon the material properties and variable electrical resistance [30, 31]. No electromechanical sensors or controls are required since those functions are intrinsic to the polymeric material. Pipe insulation is required around and over the pipe and heater strip to prevent the heat loss. The installation of such a self-regulating heater strip maintains the hot water temperature. Any heat loss is replaced only at those locations where the hot water temperature has decreased. There is no need for return circulation piping, balancing valves, circulation pumps, and controls. The energy savings result from the elimination of heat loss throughout the usual circulating pipe loop(s) that must be made up at the central heat source. Pumping power is eliminated since no circulation is required. Lower water temperatures leaving the water heater can be set, since the hot water temperature in the piping can be maintained. The application of this type of strip heater can be made to exposed hot water pipes; the greatest benefits would become available when complete building renovations are undertaken in order to permit "in-the-wall" retrofits.

Acceptance in National codes was indicated* for temperature maintenance by the self-regulating powered strip heater by, the following organizations:

- U.L. Systems Listing (File No. E58016)
- BOCA Building Code and BOCA Research Report No. 82 (Building Officials and Code Administration International, Inc.)
- Southern Building Code Congress, Compliance Report No. 8270
- Material Standard Plumbing Code

3.1.4 Training -- Maintenance, Operation, Tuneups, Repair and Modification

The information regarding adjustments, modifications, controls, and maintenance of mechanical equipment is described in many publications. For example, in [22] over 100 reference sources are listed for (all) the chapters in that book which deal with boilers. The text presents discussions of simple adjustments from fuel/air ratio (several percentage points in fuel savings) through the installation of complex auxiliary equipment (for major savings with large capital outlays). The techniques described include monitoring and testing performance, installing combustion controls, reducing heat losses, adjusting combustion conditions, and removing pollutants from stack emissions the information was from studies conducted for the Federal Energy Administration, the U.S. Department of Energy, and the U.S. Environmental Protection Agency. The chapter titles, reproduced below, indicate the scope of the practices and techniques which are <u>required by trained (often times Certified) personnel</u> to upgrade mechanical systems. For large boiler systems combined maintenance and equipment upgrading efficiency improvements and fuel reductions were claimed to yield up to 30 percent.

Chapter Subject Headings:

1. Overview of Boiler Efficiency and Controlling Factors
2. Combustion in Boiler Systems
3. Combustion in Natural Gas and Fuel Oil Burners

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* Raychem Corporation Process Division, Redwood City, California information.

- U.L. Systems Listing (File No. E58016)
- BOCA Building Code and BOCA Research Report No. 82 (Building Officials and Code Administration International, Inc.)
- Southern Building Code Congress, Compliance Report No. 8270
- Material Standard Plumbing Code

4. Boiler Testing
5. Reduction of NO_x and Other Impurities
6. Operational Procedures and Modifications
7. Efficiency Improvement Equipment
8. Boiler Maintenance Practices
9. Determination of Combustion Efficiency
10. Calculation of Boiler Efficiency (Based on site measurements)
11. Economics Evaluation

Programs sponsored by State energy offices and industrial organizations provide practical training courses. One example is the Boiler Efficiency Improvement (2 day) seminar, which has been attended by more than 20,000 personnel* in many states and Staff of the Department of Energy. In table 3.2, many of the topics listed as states and Staff of the Department of Energy. In table 3.2, many of the topics states and Staff of the Department of Energy. In table 3.2, many of the topics seminar subjects are applicable to the WAP for mechanical improvement options in multistory buildings. The course leaders indicate a 6 percent average improvement in efficiency, without further capital expenditure beyond the training, and larger savings with small investments in equipment are economically justified.

Table 3.3 shows the 1 day training seminar courses available on the subjects of Waste Heat Recovery, Energy Management Systems and Boiler Efficiency (among others) provided by the Association of Energy Engineers that are given concurrently with the annual World Energy Engineering Congress.** Such courses provide specific problem solutions and present new skills and techniques.

Local jurisdictional requirements for licensing of skilled and trained service staff are not normally replaced by training programs, and local regulations must be determined.

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* Brochure announcement -- Boiler Efficiency Institute, University Station, P.O. Box 18430-A, Baton Rouge, Louisiana 70893.

** Association of Energy Engineers, 4025 Pleasantdale Road, Suite 340, Atlanta, Georgia 30340

Table 3.2. Boiler Efficiency Improvement Seminar

INTRODUCTION OF INSTITUTE STAFF

Lecturers from
Boiler Efficiency Institute

OVERVIEW OF PROGRAM

THE ENERGY--OUTLOOK AND UPDATE
- Energy Consumption
- End Use of Energy
- Energy Resources

BOILER TYPES

- Fire-Tube
- Water-Tube
- Electric
- Other

IMPORTANT PARAMETERS OF BOILER PERFORMANCE

- Economic Considerations
- Effect on Combustion Air Parameters on Efficiency
- Effect on Inlet Water Parameters on Efficiency
- Effect on Fuel Composition on Efficiency
- Demonstration of Boiler Efficiency Improvement Trainer

PERFORMANCE OF BOILERS

- Testing Procedure for the Direct Method
  --Efficiency of Boiler
  --Summary of Measurements
  --Accuracy of Instrumentation

- Testing Procedure for the Indirect Method
  --Combustion Efficiency of a Boiler
  --Error Analysis of the Indirecto Method
  --Instrumentation for Combustion Efficiency Testing

- Examples

BOILER FEEDWATER TREATMENT
- Impurities in Water
- Measure of Water Quality
- Problems Caused by Poor Water Quality
- Water Treatment in the Boiler Plant
- Equipment Used for Water Quality Treatment

FUEL HANDLING AND TREATMENT

- Fuel Characteristics
- Fuel Problems
- Fuel Treatments
- Fuel Handling

REVIEW OF INDIRECT METHOD FOR TESTING BOILERS

- Measurements
- Instrumentation
- Adjusting Air-Fuel Ratio

BURNERS AND COMBUSTION CONTROLS

- Types of Burners--Gas, Oil, and Coal with Operational Advantages and Disadvantages of Each
- Types of Combustion Controls
- Operation and Adjustment of Controls

WASTE HEAT RECOVERY FROM BOILER

- Waste Heat Recovery, Special Considerations
- Waste Heat Recovery Systems
  --Heat Wheel Heat Exchanger
  --Heat Pipe Heat Exchanger
  --Shell-and-Tube Heat Exchanger
  --Finned-Tube Heat Exchanger
- Energy Recovery from Excessive Steam Pressure
- Energy Recovery from Blowdown
- Energy Recovery from Exhaust Gases

FIELD TEST OF A BOILER

- Demonstratsuon Test for Improving Boiler Efficiency
- Demonstration Test of Water Quality
- Inspection of a Boiler
  (Test Site Will be Near Institute Classroom)

DETERMINING PERFORMANCE OF BOILER TESTED

- Calculation of Efficiency
- Discussion of Results

BOILER SAFETY

- Flame Safeguard Controls
- Primary and Programming Controls
- Water-Level Controls
- Blowdown Controls
- High Pressure Controls and Others

HOW TO ADJUST A BOILER FOR MAXIMUM EFFICIENCY

- Air-Fuel Ratio
- Fuel-Oil Temperature
- Atomizing Properties
- Boiler Pressure
- Furnace Pressure
- Deareator
- Blowdown
- Chemical Feed
- Soot Blowing
- Multiple Boilers

IMPROVING THE EFFICIENCY OF THE END-USE OF STEAM

- Thermal Insulation
- Steam Traps
- Steam Leaks
- Drying and Other Indirect Systems
- Process Heating

Table 3.3. Association of Energy Engineers Seminars

ENERGY MANAGEMENT SYSTEMS

How to Tailor the EMS to Meet Your Essential Needs

- Programming and Scheduling
- Optimum Time Start/Stop
- Free Cooling
- Cycling
- Demand Control
- Temperature Control Optimization
- Chiller Optimization
- Data Trends
- Boiler Optimization
- Variable Air Volume Control
- Integration with Fire, Security, Communications, and Nonenergy- Related Facilities Management High, Medium, and Low Temperature Systems

How to Pick a System

- General Hardware Architectures
- Software Definitions and Selection
- Console Equipment: Types, Selection, and Location
- Data Transmission Methods
- Interface with Local Controls

EMS Characteristics

- Hardwire
- Multiplex
- Powerline Carrier
- Telephone Line
- Remote Time Sharing
- Distributed Processing Systems
- Direct Digital Control
- RTD's
- Transducers
- Remote Point Adjustments

EMS Controls of HVAC Systems

Energy Audits for EMS

Understanding Utility Rates

Security and Fire Integration

WASTE HEAT RECOVERY

Introduction and General Background

- Commercial and Industrial Estimates of Heat Recovery Potential
- Economics of Waste Heat Recovery
- Criteria for Determining Feasibility of Recovery Projects
- Utilization of Recovered Heat

Equipment Types, Processes and Limitations

- Direct Contact Heat Exchange
- Indirect Contact Heat Exchange
- Regenerative Heat Exchangers

Types of Fluids and Flow Arrangements

Utilization Equipment Used for Recovered Heat

- Waste Heat Boilers
- Heat Engines
- Heat Pumps
- In-Plant Direct Use

Efficiency Calculations and Considerations

- ASME Heat Loss Calculation
- Sensible Heat Losses and Recovery
- Latent Heat Losses and Recovery
- Other Losses
- Variations with Fuel Type and Operating Conditions
- Typical Example Calculations
- Effects of Variables

Operations and Maintenance

- Fans and Controls
- Heat Sink Temperature
- Control Parameters
- Stacks
- Water Treatment
- Effect on Emissions

Commercial Applications

- Space Heating
- Hot Water
- Case Studies: Office Buildings, Hospitals, Apartment Houses, Airports
- Other Considerations: Retrofit, Standby Losses

Industrial Applications

- Process Hot Water
- Boiler Feedwater Preheat
- Combustion Air Preheat
- Process Load
- Space Heating
- Cogeneration

BOILER EFFICIENCY IMPROVEMENT

Ways to Improve Boiler Efficiency

- Control Air-Fuel Ratio
- Add Economizer
- Reduce Scale
- Reduce Blowdown
- Add Waste Heat Recovery
- Stop Dynamic Operation
- Optimize Multiple Boiler Efficiency
- Change Boiler Pressure
- Preheat Combustion Air

Measurement of Boiler Performance

- Instrumentation
- Data
- Analysis

Water Quality

- Ph Control
- Softening
- Deareation
- Oxygen Savenging
- Hardness Control
- Blowdown
- Condensate Corrosion Protection

Demonstration of Testing and Adjusting

- Air-Fuel Ratio
- Water Quality
- Efficiency

Summary of Test Results

- Potential Energy Savings
- Economics

Boiler/Boiler System Adjustment for Efficiency improvement

- Air-Fuel Ratio
- Dearator
- Fuel-Oil Temperature
- Atomizing Properties
- Steam Pressure
- Furnace Pressure
- Blowdown
- Chemical Feed
- Multiple Boilers
- Soot Blowers

Maintenance and Operation of Boilers

- Daily Procedures
- Weekly Procedures
- Monthly Procedures
- Annual Procedures

Efficient End-Use of Steam

4. WEATHERIZATION RETROFIT EXAMPLES

The measures described in [10, 11, 33] emphasized the importance of mechanical system retrofits in multifamily buildings. Different measures were applied which illustrate the range of options available to conduct weatherization energy conservation projects. Those examples indicate, that for each site, conditions exist for which one or more retrofit actions may be applicable under the criteria.

4.1 VARIOUS SIZED BUILDINGS

In Chicago, eight buildings achieved an average 39 percent annual energy savings (without providing the basis of determination). The following building size apartment units were:

No. of Buildings	Apartments
1	4
2	6
1	7
1	13
1	19
1	25

Five of the buildings had coal fired heating plants. All had single-pipe steam systems with original radiators. Some storm windows were installed and R-40 thermal insulation was blown into spaces between the roof and topmost ceiling (common "attic" construction practice in multiunit buildings in the early 1900's in Chicago). Building temperature controls installed were air temperature sensing burner controls with programmable setback functions, high limit outdoor thermostats, and thermostatic radiator valves. The interior building thermostat was placed in the apartment furthest from the boilers; the system was balanced to minimize overheating in other apartments. The largest building had a steam cycle controller added to proportion the boiler firing in relation to the outdoor temperature.

Gas-fuel power burner replacements were used for conversion and the boilers were derated and tuned. Conversions from original coal-fired systems result in oversized heating plants, and with other energy saving measures which reduce building heat losses boilers were found to be even more oversized. The derating involved reductions of fuel and combustion air flow rates. The three smaller buildings had flue dampers installed; the larger boilers had brick flues that were too short to accommodate the dampers. One large boiler had a motor operated damper installed on the primary air intake for the burner and the combustion hatch was sealed. resulting in a sealed combustion system. Piping and boiler thermal insulation was installed. Turbulators were installed in four of the boilers but were found to limit the derating process and were removed. Turbulators, which transfer more heat from the combustion gases and lower stack temperature mostly affect the combustion (heat recovery) efficiency. The derating benefits were greater for improving total system seasonal efficiency and the stack temperatures were also lowered. Domestic hot water system improvements were made by adding thermal insulation jackets and thermal dampers. Balancing of the buildings was noted to require lengthy data compilation and feedback on conditions for the heating performance in each apartment. High costs for contracting such services were noted to possibly not be cost effective, whereas, trained building owners or staff could make compiling the required data cost effective.

4.2 CENTRAL POWERHOUSE REPLACEMENT WITH MODULAR BOILERS

An apartment complex of 19 buildings with two central gas-fired boilers for hot water supply in a circulation system and domestic hot water had the system replaced with 52 modular gas-fired boilers. Two to seven modular boilers were located in each building. The sealed pulse-combustion fired modules (commercially available units) achieve over 90 percent combustion efficiency. The two central boilers were capable of producing 16 million Btu/hr and with the system redesign the total input was reduced to 5 million Btu/hr. The individual modules were rated at 100,000 Btu/hr rating. The central powerhouse boiler room had to pump hot water through 2 miles of piping, which required electrical pump power and often required repair of leaks in the piping system. The modular boilers have low vented exhaust temperatures with discharge through plastic pipe flues, so that no additional expenses for chimneys (which would have had to be built) were required.

The hot water is piped through existing fan-coil units in each apartment unit for heating. Each apartment retained an individual thermostat temperature control. The modular feature provides operation only on an as-needed basis and proportional to the demand load; the modular operation eliminated the "all-on" or "all-off" function of the large boiler, previously in use.

Comparisons during comparable 3 month periods early in 1982 and 1983 (it was unknown if degree-day adjusted values were used) indicated reduction of about 23,000 therms. Additionally, with the removal of electrical powered circulating pumps in the underground piping about 31,000 kW were saved. With the claimed gas-fuel savings of 26.6 percent and electric power reduction of 9.5 percent the overall decrease in energy consumption was 36 percent.

4.3 HIGH EFFICIENCY FURNACES AND BOILERS

Multifamily building retrofit weatherization measures undertaken by the Philadelphia Housing Authority were described in [33]. Individual residential high efficiency pulse combustion furnaces were installed in multifamily buildings where no equipment rooms or closest spaces (to "hide" the appliance) were available. With costs of about $1,100 per furnace and 30 percent gain in efficiency (over older installed equipment) the payback period is expected to be about 3 years. The funding was provided from HUD for the energy conservation measures which also included insulation, siding, and thermally efficient windows. In another project the central boiler plant was evaluated to be inefficient and had a deteriorating underground feed distribution system. The modifications to be made will have mini-boiler rooms with four pulse combustion boilers for the hot water system for heating which are to be installed with modular configuration for proportioning the loads. Monitoring of the system performance and identification of needs for service repairs will be provided by a computer-based system. A 14 story citizens apartment building modification was reported underway where each floor will house its own boiler room with pulse combustion boilers.

5. DISCUSSION OF MECHANICAL WEATHERIZATION OPTIONS

The problems in implementing weatherization energy savings measures in multifamily housing are complex due to the diversity of the housing stock and the complexity of the systems. There is a lack of technical knowledge about how multifamily buildings can be retrofitted with predictable results. In single-family buildings the impacts of mechanical system modifications upon overall energy benefits have been integrated with heat loss reductions associated with the building shell for predictive models. Reasonable capabilities have been developed to evaluate various energy conservation steps to determine retrofit performance, and thereby provide guidelines and prioritization for energy audits and the recommendations derived therefrom.

The estimation of savings for residential multifamily energy retrofits for buildings is similar in accuracy of the state-of-the-art for commercial buildings. In [12] the investigators showed comparisons of actual energy savings with the predictions made during the pre-retrofit energy audits. From that study, figure 5.1 is reproduced, and shows "..... there is virtually no correlation between predicted and actual energy savings. Nor is it clear as yet why some retrofit projects performed much worse than predicted and others much better."

Many conventional steps for energy retrofit may be of small consequence in large residential buildings. With masonry construction and noncavity walls, improvements of thermal installation may not be feasible. Conventional storm windows may not be applicable, whereas replacement double-glazed windows may be required at higher costs. Heating systems in multifamily buildings are more complicated, probably less well maintained and require balancing to prevent overheating some apartments and allowing other units to be cold. When the building envelope can be retrofitted, the heating plant can become oversized thereby leading to inefficient on-off cycling of the system. Burner conversions for improved combustion efficiency with lowered excess air can alter hot gas flow distributions within boilers and furnaces that were designed, in some cases, for other fuels under different conditions (e.g., radiation at different peak temperatures, pressure drops across baffled sections designed for different flow rates, other hot gas to water heat transfer rates in fire tube bundles and combustion chamber refractory linings sized for combustion control by long flames). The presence of elevator shafts, light shafts, and stairways increases the "stack" effect on air movement and infiltration. Air infiltration paths and general ventilation in common areas and stairwells have been studied to some extent by dynamic mass/heat flow analyses. The example of replacing radiator valves with thermostatic radiator control valves (recognized as a low-cost improvement for retrofit) can effectively control room temperatures. However, if steam traps are not at the same time replaced or brought to a satisfactory performance condition, a considerable amount of energy in the steam can be wasted in the return piping to the boiler. The assembly of data, with empirical adjustments for modeling the aforementioned elements, for determination of the building performance with mechanical equipment operations does not appear to be available to provide guidelines for a systematic or on a step-by-step basis. The technical knowledge from multifamily building performance retrofit savings has to be systematically developed [32].

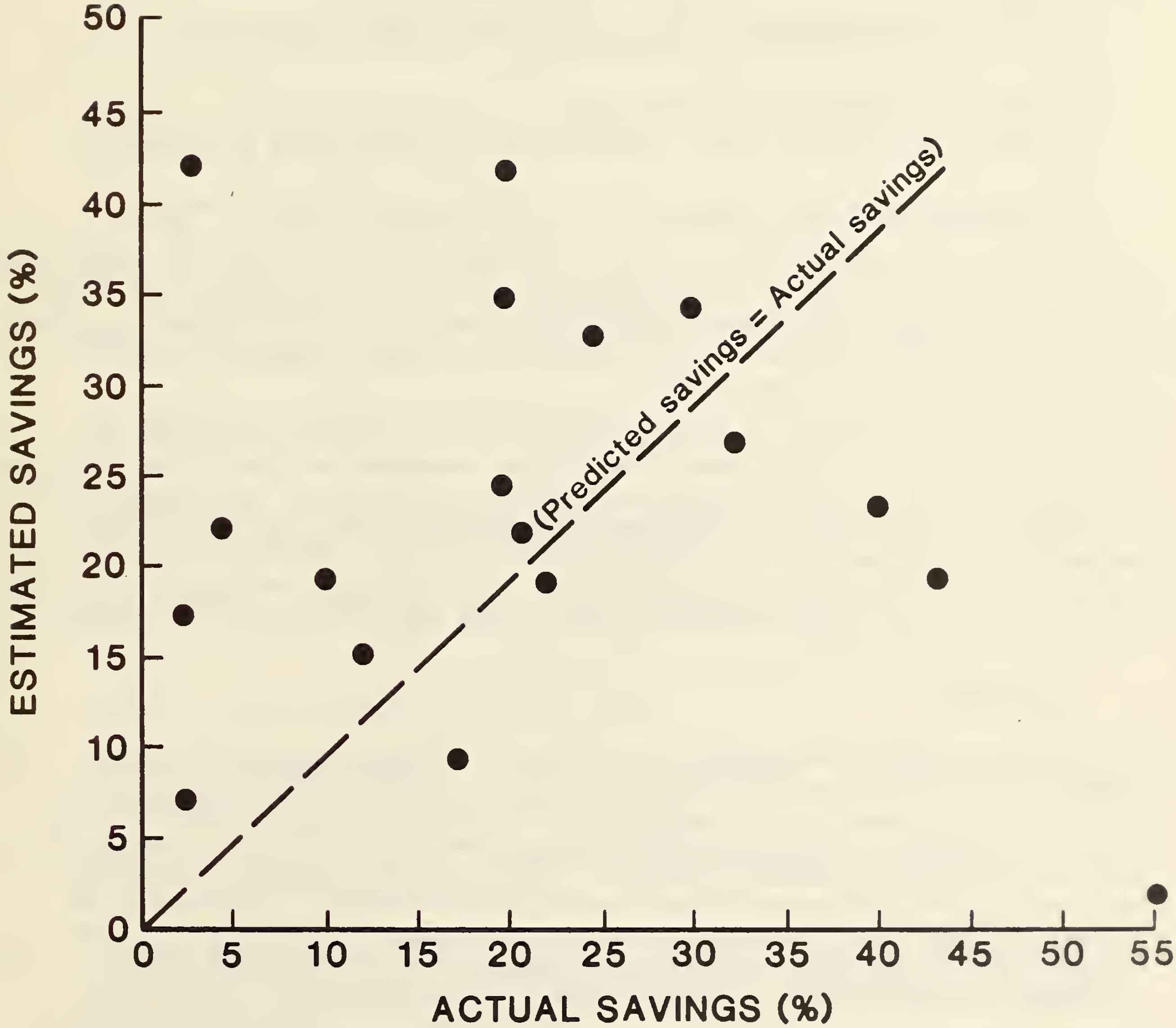

Figure 5.1 Estimated vs. actual energy savings (as a percentage of initial consumption) from retrofitting 18 commercial buildings. The data show no apparent correlation between pre-retrofit predictions and actual results. Source: Ross and Whalen, 1981.

Estimation procedures for decisions on tuneups and/or replacement can be made for furnaces and boilers from currently established procedures. These steps include:

- Measurement of stack (chimney) gas temperature.
- Condition of burner, orifices, and pilot (type and operation).
- Flame, combustion analysis.
- Refractories and thermal insulation on boiler/furnace and piping.
- Buildups on heat exchange surfaces which decrease heat transfer.

The ability to accurately predict energy savings is essential to set priorities on the investment of resources to achieve effective weatherization retrofits. The mechanical equipment measures, previously described, provide energy savings, and their selection requires that evaluations for major equipment upgrading be made through on-site inspection.

It is essential to develop initial evaluations to determine priorities of retrofit measures. The assessment techniques necessary for initial preparation of recommendations must be based upon thorough inspections. Such services can be provided by contractors and professional practitioners. As part of the mechanical system analysis the evaluation of waste heat recovery should be made. The proposed utilization and applications of thermal energy made available from heat recovery needs to be evaluated prior to the installation of such equipment.

6. CONCLUSIONS

This report provides the product and equipment recommendations for the DoE Weatherization Assistance Program in Table 3.1, "Summary of Recommended Criteria". The measures for energy conservation performance upgrading recommended inclusion of training for maintenance operation and tuneups under the program. Mechanical systems equipment, controls, energy management systems, burners, and boiler/furnace tuneup/repairs were discussed. The options for retrofit technologies indicate compliance with reference standards such as burners, burner controls, combustion chamber refractories, modifications with dampers, turbulators, and waste heat recovery devices.

The criteria developed did not include economic factors and statutory constraints under the rulemaking procedures. The need for developing predictive monetary capabilities and establishment of cost/benefit priority selection was indicated.

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APPENDIX A - WEATHERIZATION MATERIALS

The proposed rules for public comment published in the Federal Register Vol. 48, No. 215, November 4, 1983, p. 51076 lists the following "Weatherization Materials":

(1) Caulking and weatherstripping of doors and windows;

(2) Furnace efficiency modifications, limited to:

(i) Replacement burners designed to substantially increase the energy efficiency of the heating system;

(ii) Devices for modifying flue openings which will increase the energy efficiency of the heating system; and

(iii) Electrical or mechanical furnace ignition systems which replace standing gas pilot lights;

(3) Clock thermostats;

(4) Ceiling, attic, wall, floor, and duct insulation;

(5) Water heater insulation;

(6) Storm windows and doors, multiglazed windows and doors, heat-absorbing or heat-reflective window and door materials; and

(7) The following insulating or energy conserving devices or technologies:

(i) Skirting;

(ii) Items to improve attic ventilation;

(iii) Vapor barriers;

(iv) Materials used as a patch to reduce infiltration through the building envelope;

(v) Water flow controllers;

(vi) Movable insulation systems for windows;

(vii) Materials to construct vestibules;

(viii) Pipe and boiler insulation;

(ix) Heat exchangers;

(x) Thermostat control systems;

(xi) Replacement windows and doors;

(xii) Materials used for water heater modifications which will result in improved energy efficiency;

(xiii) Hot water heat pumps;

(xiv) Waste heat recovery devices;

(xv) Materials used for water heater modifications which will result in improved energy efficiency;

(xvi) Materials used for boiler repair and modifications which will result in improved energy efficiency.

The listing included the proposed expansion from the prior regulations which did not provide for mechanical and selected "architectural options in single and multifamily residential buildings." These measures were adopted as part of the final rule published in the Federal Register, January 27, 1984.

APPENDIX B - MODEL CODES

As mentioned in the body of this report, the acceptance and installation of new mechanical equipment (upgrading for partial retrofit or replacement) in buildings is specified in various nationally recognized building model codes. All or parts of code documents may be incorporated into a municipal code. In [25] a list of residential gas-fueled heating appliances was presented as those most likely to be applicable; the table B-1 is reproduced as an example. Local jursidiction requirements for compliance are to be determined, since differences and modifications may locally exist in the code documents as adopted. One example of differences cited was that appliance derating for altitudes higher than 2000 feet above sea level is specified in the National Fuel Gas Code whereas the Dwelling Code specifies an air pressure test of the installation inspection without a derating provision. Other examples of differences were noted in [25].

Municipalities that regulate the installation of gas appliances in residences generally adopt one of the model codes with or without modification. Indications of those choices are illustrated in table B-2, (reproduced from [25]). The listing emphasizes the need to determine the appropriate locally accepted practice.

Table B-1. Model Codes Governing Installation of Residential Gas-Fueled Heating Appliances

Code	Issuing Agency[a]	Comment
One and Two Family Dwelling Code	AIA BOCA IC30 SBCC	A composite of provisions drawn from other model codes and applied specifically to one and two family dwellings
Basic [Building, Mechanical, Plumbing] Code[b]	BOCA	
National [Building, Plumbing, Electrical] Code	AIA	
Code for the Installation of Heat Producing Appliances[c]	AIA	
Standard [Building, Gas, Plumbing] Code	SBCC	
Uniform [Building, Mechanical, Plumbing]	ICBO	
National Fuel Gas Code	ANS	Also known as ANS Z223.1 or as NFPA No. 54
NFPA Standards	NFPA	Pocketbook editions
No. 54 National Fuel Gas Code No. 70 National Electrical Code No. 70A Dwelling Electrical Code No. 85 Single Burner Boiler-Furnaces No. 89M Heat Producing Appliance Clearances No. 90B Warm Air Heating and Air Conditioning Systems No. 211 Chimneys, Fireplaces, and Vents		

Footnotes for Table B-1

(a) Acronyms

A.G.A. — American Gas Association
AIA — American Insurance Association
ANS -- American National Standards
ASME -- American Society of Mechanical Engineers
BOCA -- Building Officials and Code Administrators International, Inc.

ICBO — International Conference of Building Officials
NFPA — National Fire Protection Association
SBCC -- Southern Building Code Congress International

(b) Separate codes are issued for each item in the brackets.

(c) This is the analog for a National Mechanical Code.

Table B-2. Survey of Municipal Codes Regulating Installation of Residential Gas Appliances

State	Municipality[a]	Code[b]	Remarks
AL	Birmingham		
AZ	Phoenix	Uniform Mechanical Code (ICBO)	
AR	Little Rock		
CA	Los Angeles	Uniform Mechanical Code (ICBO)	
	San Diego	Uniform Mechanical Code (ICBO)	
	San Francisco		
	Santa Monica		
CO	Denver		
CT	Hartford	Basic Mechanical Code (BOCA)	
DE	Wilmington		
FL	Miami	National Fuel Gas Code (NFPA 54)	
GA	Atlanta	National Fuel Gas Code (NFPA 54)	
ID	Boise		
IL	Chicago	National Fuel Gas Code (NFPA 54)	
	Evanston		
IN	Hammond		
KS	Wichita		
KY	Louisville		
LA	New Orleans	National Fuel Gas Code (NFPA 54)	
ME	Portland		
MD	Baltimore		
MA	Boston	Massachusetts Fuel Gas Code	Adaptation of National Fuel Gas Code (NFPA 54)
MI	Detroit		
	Flint		
MN	Minneapolis	Minnesota Mechanical Code	
MS	Jackson		
MO	Kansas City	Uniform Mechanical Code (ICBO)	
	St. Louis	Basic Mechanical Code (BOCA)	
MT	Butte		
NE	Omaha		
NV	Las Vegas		

Table B-2. Survey of Municipal Codes Regulating Installation of Residential Gas Appliances (Continued)

State	Municipality[a]	Code[b]	Remarks
NH	Nashua		
NJ	Newark		
NM	Albuquerque		
NY	Buffalo	National Fuel Gas Code (NFPA 54)	
	New York City	National Fuel Gas Code (NFPA 54)	
	Syracuse		
NC	Charlotte		
ND	Minot		
OH	Cincinnati	National Fuel Gas Code (NFPA 54)	
	Cleveland	Uniform Mechanical Code (ICBO)	
	Columbus		
OK	Oklahoma City		
OR	Portland	Uniform Mechanical Code (ICBO)	
PA	Philadelphia	National Fuel Gas Code (NFPA 54)	1969 version of NFPA 54 (i.e., ANSI Z21.30)
	Pittsburgh	National Fue Gas Code (NFPA 54)	
RI	Providence		
SC	Columbia		
SD	Rapid Center		
TN	Memphis	Basic Mechanical Code (BOCA)	
TX	Dallas	Uniform Mechanical Code (ICBO)	
	Houston	Uniform Mechanical Code (ICBO)	
UT	Salt Lake City	Uniform Mechanical Code (ICBO)	
VT	Burlington		
VA	Alexandria		
WA	Seattle	Uniform Mechanical Code (ICBO)	
WV	Charleston		
WI	Milwaukee		
WY	Casper		

(a) For each state in the contiguous U.S. at least one municipality is listed having a high number of residential gas "househeating" customers (relative to other localities in the state) to indicate potential replacement/retrofit markets for advanced technology equipment.

(b) Entries appear only for municipalities surveyed.

APPENDIX C - BOILER RATINGS

The determination of ratings of older boilers may not be readily obtained due to the loss of identification tags or coverings that prevent determination of surface markings. For some equipment the manufacturers may no longer be in business and therefore other sources of data are required. Prior to development of modern testing and rating codes, such as those of the Institute for Boiler Ratings (IBR), uniform nomenclature and units did not exist [9]. Referenced sources of information are provided below (reproduced from Chapter 28 -- Boiler Ratings).

American Boiler Manufacturers Association, Industry Standards and Engineering Information--Steam Generating Equipment (1958); Technical Committee of Packaged Firetube Branch, Packaged Firetube Boiler Ratings (1959).

American Gas Association Laboratories, Directory of Approved Appliances and Listed Accessories (semiannual).

American Society of Heating, Refrigerating, and Air Conditioning Engineers, Guide (annual).

American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code; Power Test Codes.

American Standards Association Approval Requirements, ASA Z21.10 Gas Water Heaters; ASA Z21.13.1 Central Heating Gas Appliances (Steam and Hot Water Boilers, V. 1); ASA C72.1 Household Electric Storage Type Water Heaters.

Beacon Boiler Reference Book, Heating Publishers, Inc.

deLorenzi, O., Combustion Engineering. Combustion Engineering, Inc. (1947).

Fuel Oil News Boiler Rating Handbook, Oildom Publishing Co.

Hartford Steam Boiler Insurance and Inspection Co. literature.

Hunter, L. N. "Most Heating Boilers Selected on the Basis of Their Net Ratings," Heating, Piping, and Air Conditioning, February 1956.

Institute of Boiler and Radiator Manufacturers, IBR Testing and Rating Code for Low Pressure Heating Boilers; IBR Ratings for Cast-Iron Boilers; IWH Testing and Rating Code for Indirect Storage and Tankless Water Heaters, External Type, Tested in Tank; IWH Testing and Rating Code for Indirect Tankless Water Heaters, Tested with Boilers.

Kent, R. T., Kent's Mechanical Engineers' Handbook, John Wiley & Sons, New York.

Marks, L. S. Mechanical Engineers' Handbook, McGraw-Hill, New York.

Mechanical Contractors Association of America, "Net Load Recommendations for Heating Boilers" and "Testing and Rating Code for Boiler-Burner Units," Engineering Standards, Part II (annual); Private Communications.
Pape-Swift Boiler Reference Books, Color-Art Printing and Stationery Co., Kirkwood, Mo.

Steel Boiler Institute, SBI Rating Code for Steel Boilers; Private Communications.

Stoker Manufacturers Association, Uniform Stoker Ratings.

Titusville Iron WOrks Division, Struthers Wells Corp., trade literature.

U.S. Department of Commerce, Simplified Practice Recommendations for Steel Firebox Boilers and Steel Heating Boilers (R 157-50).

The reference [9] suggests that the Beacon Boiler Reference Book, Fuel Oil News-Boiler Rating Handbook, and Pape-Switft Boiler Reference Books may be useful. Although many of the applications were in equipment sizes appropriate to utility installations the lower levels of performance rating values could apply to building system plants. The "Guide" of the American Society of Heating, Refrigeration, and Air Conditioning Engineers also provides a recommendation for boiler heating surface and steam generation in units of equivalent square. foot of steam radiation (usually denoted as EDR). Other sources are the American Boiler Manufacturers Association (ABMA) and the Steel Boiler Institute (SBI). The Mechanical Constractors Association (MCA) formerly the Heating, Piping, and Air Conditioning Contractors National Association, had the two codes for:

1. MCA Testing and Rating Code for Residential and Small Commercial Package Boiler Units -- for testing and rating small and intermediate sizes of heating boilers with integral burner units fired with fuel oil.

2. MCA Testing and Rating Code for Commercial Package Boiler Units -- for rating commercial sizes of steel heating boilers fired with oil- or gas-fuel.

The figures C-1 and C-2 (from [9]) indicate the type of boiler net-load information of older equipment.

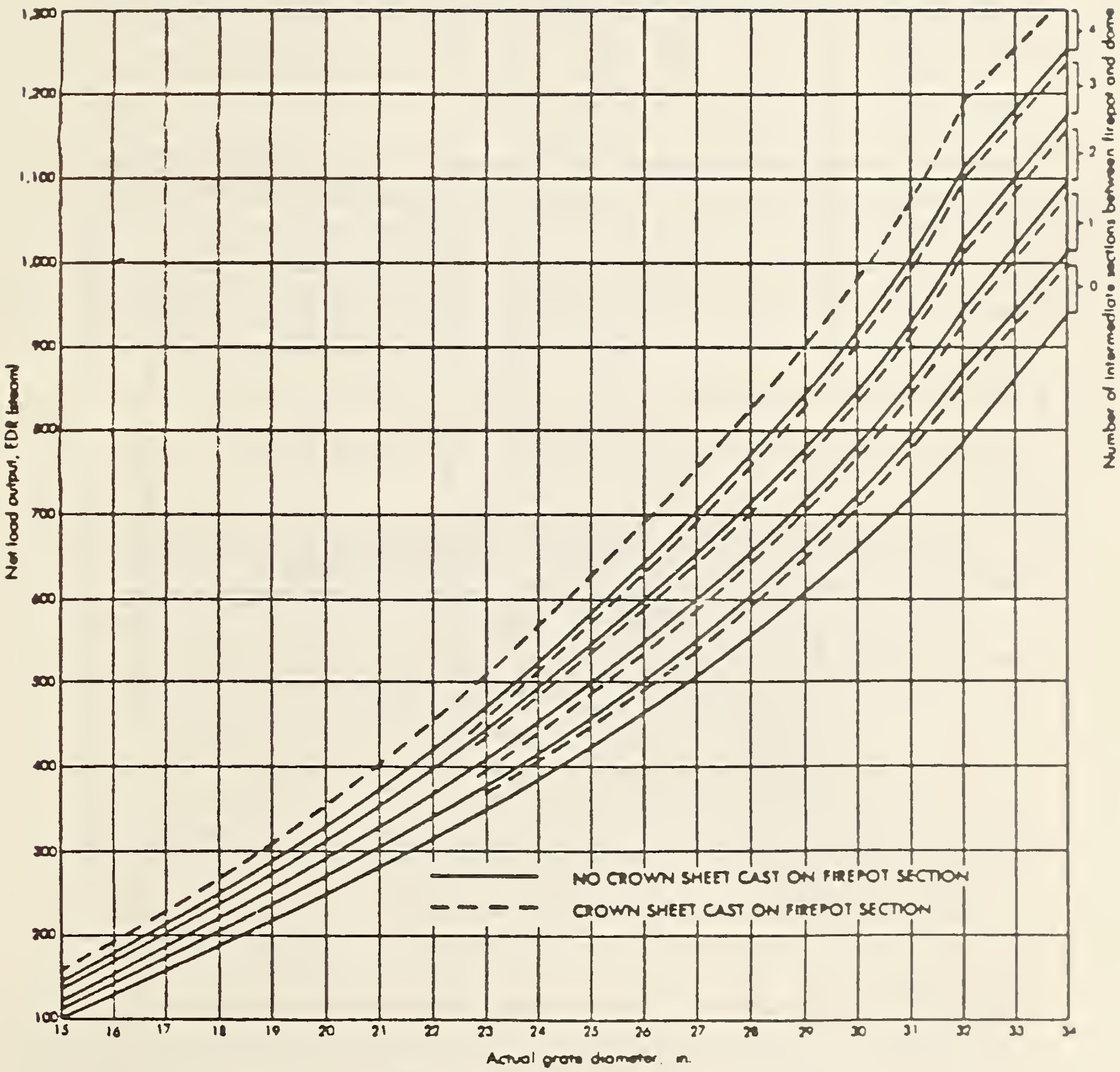

Figure C-1. Net load recommendations for obsolete round cast-iron boilers based on 13,000 Btu per lb of hand-fired coal, in 70°F ambient. (From MCA, "Net Load Recommendations for Heating Boilers.")

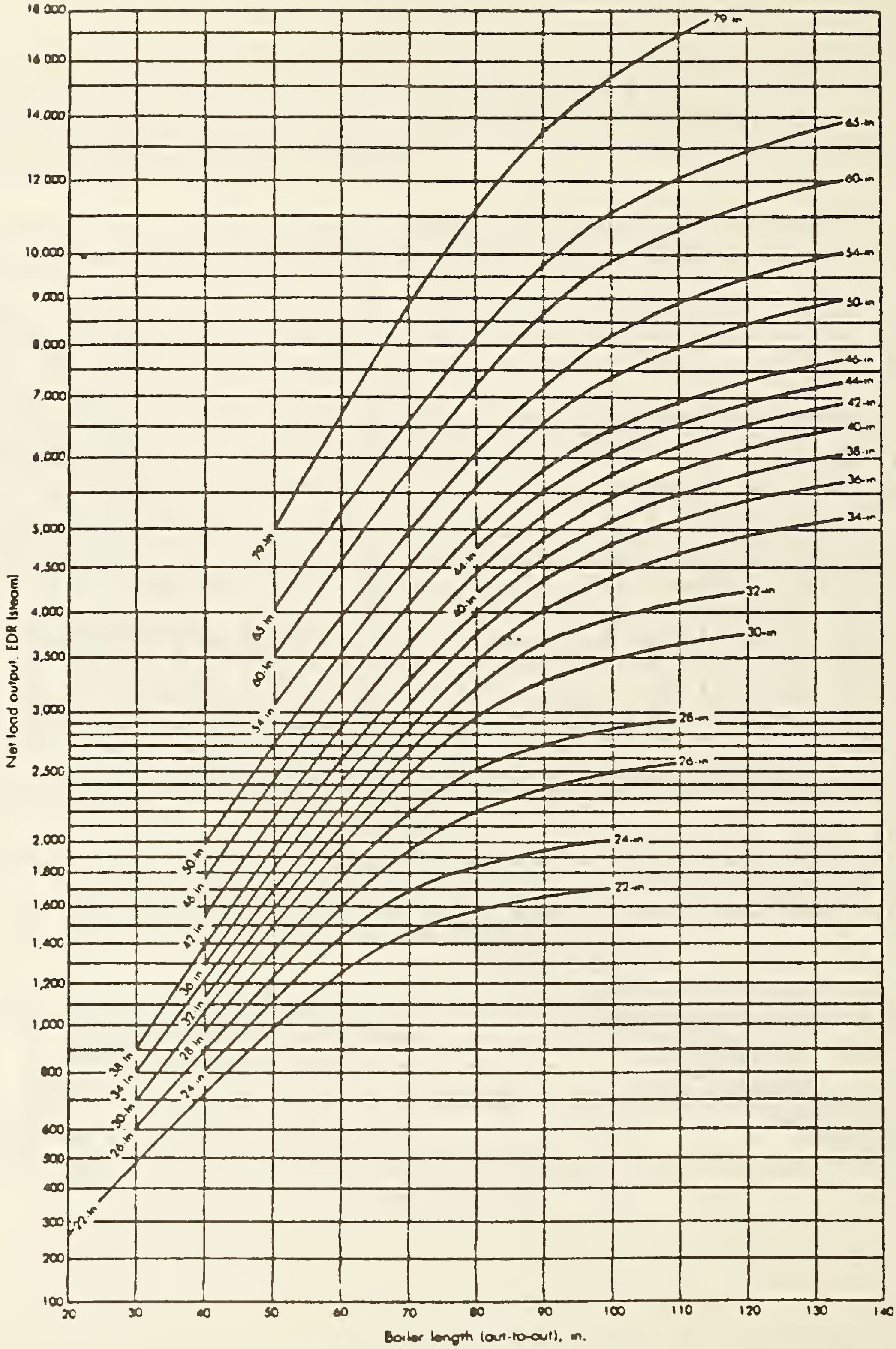

Figure C-2. Net load recommendations for obsolete square (sectional type) cast-iron boilers

Individual curves are for grate widths from 22 to 79 in.; load recommendations based on 13,000 Btu per lb of hand-fired coal, in 70°F ambient. (From MCA, "Net Load Recommendations for Heating Boilers.")

APPENDIX D - CODES, STANDARDS, ORGANIZATIONS, AND MARKINGS

D.1 NAMEPLATES, SYMBOLS, AND IDENTIFICATION MARKINGS

Larger scale mechanical equipment has been, and continues to be, guided by standardization and regulation through various interests for construction and inspection. Many nameplates or markings are used with identifying symbols or stampings to show that requirements have been met, often to indicate a seal of approval.

For example, gas appliances and accessories may be entitled to bear the Laboratories Certification Seal of the American Gas Association. The symbol provides the manufacturer's representation that the unit is constructed according to the design certified by the American Gas Association Laboratories and found to comply with generally accepted national standards. Jurisdictions may require installed appliances to comply with American National Standards and may accept AGA certification as evidence of such compliance.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2939	2. Performing Organ. Report No.	3. Publication Date

4. TITLE AND SUBTITLE

CRITERIA FOR MECHANICAL SYSTEMS IN MULTIFAMILY BUILDINGS FOR RESIDENTIAL WEATHERIZATION OPTIONS

5. AUTHOR(S)

Lawrence S. Galowin

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Department of Energy
Office of Weatherization Assistance
Forrestal Building
Washington, D.C.

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The National Bureau of Standards (NBS) prepared the original criteria and list of eligible retrofit options adopted for energy conservation by the Department of Energy Conservation in Existing Buildings Act of 1976. NBS was requested to review, update, and expand the criteria and list of retrofits for 1984 ammendments to the regulation. This report presents the criteria and reference standards for retrofit options of mechanical equipment and systems in multifamily buildings.

Mechanical systems equipment, controls, energy management systems, burners, and boiler/furnace tuneups/repairs were included. The options for retrofit technologies for equipment replacement components include items such as burners, burner controls, combustion chamber refractories, modifications with dampers, turbulators, and waste heat recovery devices. The criteria developed did not include economic factors and statutory constraints under the rulemaking procedures.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

boiler/furnace performance upgrading; energy controls; energy conservation; mechanical building equipment; replacement burners; weatherization; tuneups and repairs for multifamily building equipment.

13. AVAILABILITY

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☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

XX Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

77

15. Price

$11.50