Glass units are usually rated between 600 and 3000 watts, for standardized voltages of 120, 208, or 240 volts. Starting current for some types exceeds normalized current by 10 to 50 percent. However, there are types with substantially no current surge. Frame sizes vary from about 30 x 24 in. for 1000 watt size to 42 x 6 in. for baseboard models, and are arranged for recessed or for surface mounting. Thermostats integral with the unit are optional. Portable units with cord are available.

Radiant panels using tubular elements built or cast into extended aluminum panels have emissivity characteristics similar to glass panels.

Electric Floor Panels

Resistor cables of the same type used for ceilings are used for floor panel systems in concrete slabs. Precautions to be observed in construction of slabs for panel heating are covered in Chapter 12 and 30. Non-insulating cement finish 1⅛ in. thick is poured and troweled above cables fixed to a minimum 3 in. slab. In some areas, cables may be stapled to wood nailing strips fixed in the surface of the rough slab. When the slab is made of light-weight insulating concrete, cables may be stapled directly to the slab. Alternative special anchors are available to hold the cable at proper spacing during pouring, and are held by nails driven by hand or powder impact drivers. Otherwise, periodic temporary fastening with daubs of cement, plaster of Paris, strips of masking tape, or other non-conductive material must be used.

With monolithic finish, nailing strips are omitted and the cable is strung on frames with nail spacers; frames are removed when enough concrete has been poured to hold the cable in place. If desired, magnesite flooring, ceramic tile flooring, asphalt tile, or wall to wall carpeting may be used on the floor. Insulating-type concrete may be used below cable, but must not be used around or over cable.

Central Hot Water Systems

Heating systems of hot water type using radiators or convectors, discussed in Chapter 28, may be operated using an electric hot water boiler containing immersion elements (resistors). Resistors may be interlocked to prevent energizing when the circulating pump is not operating. The boiler water holding capacity should be sufficient to minimize cycling.

For off-peak operation where electric rate considerations justify, a water heating tank of large storage capacity may be employed. The system may be designed for a water temperature of 250 to 275 F at pressures up to 75 psig, with suitable piping systems for this pressure. An automatic valve may provide 140 to 160 F water at the pump by mixing hot water from the tank with cooler water from the return main. Another method employs the *flash* principle, withdrawing water at high storage temperature into a low-pressure separating chamber where steam is obtained as a result of the pressure reduction; however, power for pumping is substantially greater with this steam-accumulator method. Thermal insulation on boiler tank and piping must be adequate to minimize losses. High investment, space required for equipment, and loss of much of the convenience and economy of operation available with other forms of electric heat, tend to limit the application of this type of system.

Central Warm Air Systems

Resistors mounted in a frame or housing may be fitted into the main duct with a fan forcing air to heated spaces through branch ducts, or may replace the heat exchanger of fuel-fired furnaces to convert them to electric operation. While lower in first cost, much of the convenience and economy of operation available with electric heat locally applied in space being heated is lost by such central system applications.

Duct Heaters. Resistors mounted in a frame or housing may be fitted into branch ducts leading to the various heated spaces. In addition to providing individual room control of heating, these heaters provide a means of local reheat for summer control of humidity, when combined with air conditioning.

Heat Pump Systems

Heat pump systems are discussed in Chapter 39. Heat pump systems using air as a heat source lose capacity rapidly as the outdoor temperatures decrease, while water and earth heat source pumps sized for cooling also frequently reach the *balance point* at outdoor temperatures above outdoor design. Deficiency at temperatures below the *balance point* can be supplied by supplementary electric resistance elements in the unit, ducts, or spaces served. When these heaters are placed in individual ducts or spaces rather than centrally, the electrical demand may be minimized, the individual spaces may be maintained at slightly different temperatures, and local reheat during the cooling cycle is readily available. An alternative provision for cold weather peaks is thermal storage in chemical salts and by other devices. Such processes are still in the development stage.

The installed cost of residential heat-pump systems usually is higher than that of resistance types.

CALCULATING CAPACITIES

The procedure outlined in Chapter 12 for calculating the heating load may be used for electric systems. Load expressed in Btu per hour is converted to kilowatts by the divisor 3413 Btu per kilowatt. The National Electrical Manufacturers Association has published the *NEMA Manual for Electric House Heating* describing methods and giving heat loss factors for calculating load directly in kilowatts. All the energy applied to a resistor transforms itself into heat, unaffected by temperatures of the surrounding air and of surfaces receiving radiated heat. However, both electric power input and heat output are directly affected by voltage at the resistor terminals, being proportional to square of the voltage. Thus, a resistor rated 1000 watts at 240 volts, if used on a circuit at 220 volts, delivers 840 watts or 16 percent under the rated value, while at 208 volts the shortage is 25 percent.

The arbitrary addition of a percentage *safety margin* on the calculated heating load is not recommended. Such practice would increase the peak electric demand and often the cost of electric service.

The most economical electric heating systems from an operating standpoint are of decentralized type, with a thermostat provided on each unit or for each room. This permits each room to compensate for heat contributed by auxiliary sources such as sunshine, lighting, and appliances. This arrangement also gives a better diversity of the power demand due to non-coincidence of electric load from all units of an installation. Manual switches are often provided to permit cutting off heat or reducing temperature in rooms when not in use. When such operation is practiced, consideration should be given to provide adequate capacity for warm-up as compared to a system maintaining a constant temperature.

For sake of economy buildings intended to be heated electrically should be well constructed, have adequate thermal insulation and storm windows or double-glazed windows in more severe climates to minimize heat loss and weather-stripping to minimize infiltration. The relatively high electric cost for thermal energy, about \$5.40 per million Btu at \$0.018 per kwhr, for example, as compared with about \$1.50 for oil at \$0.16 per gal when utilized with 70 percent efficiency, gives economic justification for substantial expenditure to reduce heat consumption. The large majority of dwellings heated economically by electricity have heat factors (quotient of seasonal energy consumption in kilowatt hours, divided by degree days and by volume of gross heated space expressed in thousands of cubic feet) between 0.15 and 0.3. The features necessary to hold consumption within these limits result in construction that for 5000 degree-day climate with 0 F outdoor design temperature, gives a calculated heating load of 3400 to 5100 Btu per hr per 1000 cu ft gross volume. Heat factors up to 0.4 are not uncommon, but experience shows that such high heat requirement may result in excessive operating cost. General practice is to provide adequate thermal insulation with electric heating installations.

POWER CONSIDERATIONS

Rates for Electric Service

The cost of electricity varies due to several factors. The main elements are the annual charges, including taxes, on capital invested and those expenses necessary to keep the electric utility system at all times in a state of *readiness to serve* the load. The cost of generating the energy is secondary. Electricity is not stored, but must be produced instantaneously when and as required by the user. Consequently, the time of power use, both daily and seasonally, and relation between rate-of-use or demand and the energy consumed within a period (load factor) have large effects on costs and the rates charged. Special low rates sometimes are available during certain prescribed *off-peak* hours of use, when the system load is low.

Space heating is a load whose magnitude is determined basically by weather, and is affected to a much lesser extent by the electric customer's use of his premises. Most of the heating loads in a region occur simultaneously, thereby tending to create peaks for which the capacity of the electric system must be adequate. Accordingly, rates contain, in one way or another, charges both for demand and energy. Demand may be indicated directly by a demand meter or be derived from manufacturers' rating data shown on nameplates of the heating equipment. In block-type rates, where demand is not specifically mentioned, it is in part reflected by higher charges per kilowatt-hour in the earlier blocks.

Control of Electric Demand

To obtain electricity for space heating at minimum cost, it is necessary to keep the user's kilowatt demand as low as possible, by provisions in original design of the installation and by judicious methods of operation. Excess heating capacity should be avoided, but without jeopardizing satisfactory performance in cold weather. A variety of control methods can be applied to minimize both demand and consumption. Decentralized control with a thermostat in each room or on each heating unit, together with manual switch to cut off any unoccupied room, is one method. Sequence switching whereby electric service to individual rooms or circuits is shifted in rotation by an automatic timing device and sequence is modified by outdoor thermostat or by total electric load, is another.

Load-limiting controls of several types have come into use. These are generally arranged to measure the customer's total power demand, which for a residence may be grouped as lighting and miscellaneous appliances, refrigerator and water heater, cooking range, and the space heating system. When the demand exceeds a preset value, one or more heating circuits are cut off progressively in rooms least affected by the interruption. Experience shows that with electric floor or ceiling panel heating, temperature drop occurs slowly, at the rate of about 1 deg per hour for concrete slabs and 2 deg for plaster construction or rigid panels properly backed with thermal insulation. Moreover, electricity consumed by lighting, appliances, and cooking ranges is contributing some useful heat at such times.

Another form of limiting control for 120/240-volt 3-wire circuits provides complete or sequence transfer of space heating units from 240 volts to 120 volts, thereby reducing the electric input to one quarter whenever the total load or general-service component exceeds a preset limit. This method lends itself to use of an outdoor thermostat actuating a relay, whereby in mild weather the entire heating system operates at 120 volts and with lengthened cycles obtains more uniform room temperature. For reducing temperature at night, if desired, a clock-operated master thermostat can be provided to lower the heating-system voltage. On some electric utility systems, centralized control by means of a pilot-wire or carrier-current actuating a relay is applied to house-heating installations.

With any type of control, time-delay relays should be used in order that upon restoration after an emergency service interruption or whenever a master thermostat calls for heat, the individual circuit or units will come on non-simultaneously over a period of a few minutes. This is advisable especially for types of resistor units that have a power input, when cold, as much as 50 percent above the rated value at normal operating temperature.

Operating Costs

With increased numbers of electric heating installations, operating cost estimates and experience records are accumulating. Experience records are indicating that actual consumption may be less than conventional calculations and comparisons would indicate. This is particularly true with thoroughly insulated structures or for applications having short hours of maintained temperatures and long reduced temperature periods.

The *NEMA Manual for Electric House Heating* applies the following formula for estimating the cost of electric heating:

$$\text{Annual kilowatt-hour consumption} = \frac{HL \times DD \times C}{TD}$$

where

C = constant (see text below).
HL = heat loss of building, kilowatts.
DD = annual degree days for area.
TD = difference between indoor and outdoor design temperature, Fahrenheit.

The constant C depends on a number of variables such as weather conditions in the locality, orientation, design and construction of the building, living habits of the occupants,