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Sizing Heaters and Steam Requirements for Domestic Hot Water Systems -Hotel-

An adequate supply of hot water is a must in motels, hotels and other types of multiple dwellings. Improper sizing and design of hot water supply systems will invariably lead to problems such as dissatisfaction of the customer due to undersized systems or wasteful economics of oversized systems.

The report is based on recommendations of The ASHRAE Applications Handbook, good practice of major USA manufacturers of the instantaneous, semi-instantaneous and storage heaters, and the experience of the engineering staff of The Alstrom Corporation.

Although this report is limited to analysis of service, hot water supply at minimal initial investment and maintenance cost. Hot water consumption depends on the hotel size, occupancy, auxiliary services, and to a degree, the level of luxury provided by the hotel. While consumption of hot water does not depend on the of water heater used, the rate of hourly energy consumption will vary widely from one type of heater to another. The same building can get the necessary hot water supply from a large boiler and a small instantaneous heat exchanger, or from a large storage heater and a small boiler. A hot water storage heater will reduce the size of the boiler; minimize hourly steam rate, gas, oil or electricity supply as opposed to an instantaneous and semi-instantaneous water heater. Of course, the daily water and energy consumption does not depend on the type of the heaters, but it will definitely affect the initial cost of the system and its maintenance.

The correct sizing of boilers and heat transfer equipment for hotels required the understanding of the basic system design. This report provides a short review of the major considerations for the end user and designer.

The review is restricted to guest room systems that utilize hot water for lavatories, showers, bathtubs and basins. Although consumption patterns in guest rooms are subject o wide variations, the general classification can be achieved depending on the type of hotel. Kitchens and laundries vary greatly, and always re a subject to custom design. Fortunately, hot water demand for kitchens and laundry rooms for a specific hotel can be estimated by the hot water consumption of equipment utilized in these facilities.

In addition, the hotel engineering community prefers the separation of the kitchen and laundry due to the severe impact of laundry start up demands that often coincide with the day's peak guest room consumption.

Temperature Regulators and Steam Traps

By definition, service water heaters are designed to heat cold water to desirable temperature where demands are intermittent and are subject to frequent fluctuations. Selection of the temperature regulator is important decisions that will affect the temperature expand during the load variations, and, in to some degree, determines the size of the heating section. Indeed, the size of the heat transfer equipment depends on the actual steam pressure that equals to temperature regulating valve.

There are three types of temperature regulating valves (TRV). First: Self-contained vapor tension, Pilot-operated and Pneumatically-operated. Each has unique advantages and disadvantages. Temperature regulator installations vary from systems with large storage tanks that change temperature gradually as hot water is drawn off to instantaneous shell and tube heat exchanges that require a fast temperature response time. Because the volume of water in the tubes of the instantaneous heaters is small, variable flow causes uncertain temperature fluctuations.

Self-contained (TRV) or pilots may require 10 to 80 seconds to respond to a temperature change. This can cause momentary temperature fluctuations until the regulator is stabilized to a changed condition. The use of a self-contained (TRV) with light spring decreases the temperature span from a closed to an open position to approximately 6 deg. F. for ¾" valve, 10 deg. F to 1 1/14: valve and 13 deg. F to 2" valve. Actual span is determined by the fill fluid and spring combination that varies with the adjustable temperature range selected. The short stroke characteristic of the TRV design minimizes temperature span.

If self-operated (TRVs) must be used (air or electricity is not available) and a smaller span is essential then further improvement may achieved by using a larger valve, half opened at peak steam flow. Due to the linear characteristic of the sliding gate valves, the use of a larger valve will reduce the differential temperature needed to achieve required steam flow when the water flow is suddenly changed.

Pilot-operated regulators offer the advantage of higher flow rates and larger sizes, however, are more expensive. In addition their control may be erratic if they are not sized perfectly for flow rates and operating pressures. Please note that minimal differential pressure is not required for proper operation of the pilot-operated self-contained temperature regulating valve. The use of pilot-operated regulators should be reserved for use only where compressed air or electrical supply is not available.

Pneumatically-operated Control Valves with temperature controller usually respond faster to changed conditions and hold a closer set temperature. Pneumatic temperature controllers with adjustable proportional band (span) and reset function can continuously maintain the hot water temperature very close to the set point. Less expensive bi-metallic models are available in accuracies similar to self-contained TRV, providing the advantage of quicker response. These less sophisticated controllers are very popular due to reasonable cost. Pneumatically-operated control valves with temperature controller, like the self-operated TRV, do not require minimal differential pressure for proper operation.

All types of regulators do not have an immediate response. If the close temperature control is required, the addition of a thermostatic mixing valve will temper the water temperature within 2-3 deg. F., lower steam temperature that increases the size and cost of the heat transfer equipment.

The following differential pressure psi may be recommended for self-contained and pneumatic TRV.

Inlet Pressure	**Outlet Pressure (psi)**
5	1. 9
10	5
14.2	10
28.4	17.1

42.7	27
49.8	29.9
71.1	46.9
99.5	64
144.2	106.7

Pilot-operated valves require a minimum differential pressure about 24.2psi.

The Float & Thermostatic Traps are commonly used to discharge air and condensate from heat exchanges, preventing steam from entering return piping in steam heating systems. An undersized steam trap will cause condensate to back into the heat exchanger and result in a steam hammer. It is a good practice to oversize a steam trap 2(x) times the maximum capacity of the temperature regulator. The steam trap selection is based on a differential pressure, which equals to operational pressure in the heat exchanger less back pressure of the condensate line.

Instantaneous Hot Water Heaters

Instantaneous water heaters are selected to heat water during the peak momentary consumption at the maximal temperature rise. A boiler, steam and condensate piping, TRV and other accessories are selected to satisfy this maximal heat demand. With a drop in heat demand, the TRV will reduce steam supply by controlling the hot water temperature.

The most common design of these heaters is shell and tube heat exchangers where the water is heated as it flows through the tubes (Alstrom ECO-Pack Package). The tube side of the instantaneous water heaters is constructed from stainless steel, copper or other nonferrous alloys. Since steam is not corrosive fluid, the shell is constructed from carbon steel. The instantaneous water heaters have relatively small size and can be easily installed, repaired or replaced in the boiler room with limited access. Due to their small size and low cost of materials used, instantaneous water heaters are inexpensive. The optimal heat exchanger will be one with maximal permitted length because of its smaller diameter. High velocity of water improves heat transfer rate and prevents scaling. This type of heaters requires the largest source of steam to compare with other heaters.

Steam consumption can be reduced by sub-cooling the condensate (Alstrom Steam Saver Package). This method results in smaller diameter of piping and accessories, and it reduces heat loss from the condensate line. By sub-cooling the condensate, heat loss from the flash steam, occurring after the steam trap, is prevented, resulting in substantial energy savings and preventing water hammer in the condensate line.

Semi-Instantaneous Water Heats without Storage Section

Several domestic manufacturers of Semi-instantaneous heaters use the shell as a storage section for hot water. Since the ratio of storage capacity to recovery is measured in seconds, they perform as instantaneous heaters. Therefore, their commercial name may result in certain confusion.

The storage and heating sections of these heaters are constructed from corrosion resistant materials, In addition, a circulating pump is provide in order to reduce temperature fluctuations of the outgoing water. The manufactures of semi-instantaneous water heaters claim that outlet water temperature is maintained within 4 deg. F due to continuous circulation of water by the pump. Unfortunately, there is no explanation whether this rang is maintained at steady flow rate or is the temperature span from closed to open TRV.

Usually, hot water systems for hotels are designed to have hot water available continuously at the fixtures by using return piping. In this case the circulation pump does not provide any advantage, and the use of semi-instantaneous water heart with very small storage section is hardly justified. High cost of materials, circulating pump, electrical panel and power supply significantly increases the cost of these heater compared with instantaneous water heaters.

Compact Water Heaters

The Compact Water Heaters have storage section, designed by manufacturers to accumulate heat in order to meet the surges of hot water demand for a limited period. Since there is no need to satisfy momentary heat demand, these heaters require significantly smaller source of steam than instantaneous water heaters.

The Compact Water Heaters have similar design to semi-instantaneous Water Heaters. In this case, a circulating pump is useful to intensify heat transfer and prevent temperature stratification of the stored water. As a result, 90% of the storage section is assumed to be useful.

Sizing of Instantaneous and Semi-Instantaneous Water Heaters without Storage Section

ASHRAE Fixture Units Method

The fixture Units are assigned to each fixture using hot water and totaled. The empirical Modified Hunter Method, represented by curves for various building types, estimates the required hot water flow rate (WFR). Since the reading of data fro the curve is inaccurate, the following formulas were developed to interpolate the curve for hotels.

Fixture Units

0-75	WFR = (36 + 1.280 x FU) x 0.264gpm
75-400	WFR = (107 + 0.333 x FU) x 0.264gpm
More than 400	WFR = (156 + 0.210 x FU) x 0.264gpm

ASHRAE Applications Handbook recommends the following date.

Fixture Units (FU)

0.75	Basin, Private Lavatory
1	Basin, Private Lavatory
1.5	Tub & Shower
5/per 250 units	Dishwasher
2	Barber basin
2.5	Beauty parlor basin
1.5	Kitchen sinks
2.5	Pantry sinks
2.5	Service Sink

Example: 200 Room Hotel

No. Fixture	**Type of Fixture**	
200	Private Lavatory	200 x 0.75 =150
10	Public Lavatory	10 x 1= 10
20	Private Shower	20 x 1.5 = 30
186	Tub & shower	186 x 1.5 = 279
6	Beauty parlor basin	6 x 2.5 = 15
4	Barber basin	4 x 2 = 8
Total		492

Net Water Flow Rate

(156 + 0.21 x 492) x 0.264= 68.46gpm or 4107,6gph

Maximum Hourly Water Capacity per Unit (Room)

4107,6 / 200 = 20.54gph

Net Heater Capacity-Peak Heat Demand

4107,6 x 8.345 x 1 x (149-40) = 3,736,293 Btu/hr

Steam Rate

3770lbs/hr

To make preliminary estimates of hot water demand when the fixture count is not known, more general recommendations may be used based on the type of building and number of customers.

The preliminary hot water demand for hotel or motes is 2.5 Fixture per room.

Estimated number of Fixture units:

FU = 2.5 x 200 = 500

Net Water Flow Rate

(156 + 0.21 x 500) x 60 x 0.264 = 4134.2gph

Comparisons of the flow based on actual fixture count to the flow obtained from the preliminary estimate shows very close results. Please not, that there is a possibility of preliminary estimate being twice as large then the actual fixture count.

Pressurized Hot Water Storage Heaters

Pressurized Hot Water Storage Heaters use vessels of certain volume. They consist of a storage section and an immersed tube bundle. Steam or boiler water passes through the tubes of the tube bundle. The incoming cold water enters the bottom of the storage section where it is mixed with stored water and heated by a natural convention. Due to dilution by the cold water entering the heater, only 60 to 80% of the storage section is assumed to be useful.

During the day, flow rate of water entering the pressurized vessel, equal to the flow rate of the water leaving the vessel. Although flow rate of the incoming water varies, the heating section is selected for relatively steady average water rate called recovery. If water consumption equals the recovery rate, than the average temperature of the stored water remains the same. When the water demand is increased, the average temperature of the stored water is decreased. And when the water demand is decreased, the average temperature of the stored water is again increased. Since the recovery is significantly smaller than peak water demand, the use of storage heaters requires smaller boilers, piping and accessories.

Storage heaters require the smallest source of steam in comparison with other heaters. At the same time, they required large space in the boiler room. If the heating section or circulating pump is damaged, the stored water has to be drained. In order to prevent corrosion, inner surface of the storage section is line with epoxy, cement or other types of coatings. This protective layer is prone to cracking and, therefore, requires periodical inspection. Due to thermal inertia of the stored water temperature control is less problematic, and self-contained valves will provide inexpensive and accurate result. Storage heaters are selected to maintain a reasonable constant supply of steam or boiler water, but the actual water flow rate depends on hot water demand during the day. An analysis of heat consumption patterns in hotels and other type of dwellings shows that there are three heat consumption periods as follows: heat accumulating heat discharge and standby.

Heat Accumulating

Heat Recovery is larger than Heat Consumption. The mean temperature of the stored water is rising. The TRV is totally open to provide maximal supply of steam. When the set temperature is achieved, the steam supply is reduced to minimum to compensate the heat loss.

Heat Discharging

Heat Consumption is larger than Heat Recovery. The mean temperature of the stored water is dropping. Again, the TRV is totally open to provide maximal supply of steam.

Standby Period

When the stored water reaches the set temperature of TRV, steam consumption will be reduced to compensate for the heat losses from the storage heater and the return price.

In conclusion, the method of hot water storage in the pressurized vessels is based on

1. Constant volume of stored water
2. Variable incoming and outgoing water flow rate
3. Variable temperature of stored water

Heat, stored in the Pressurized Storage Heater

$Q(a) = M*Cp*(Ts-Tm)$ Btu

Where:

Ts-set temperature of the TRV that is maximal permitted temperature of the stored water
Tm-minimal permitted temperature of the stored water
M-Net Weight Storage Capacity of the Heater (lbs)
Cp-specific heat of water

As follows from this equation, heat stored in the Pressurized Storage Heater does not depend on temperature of the incoming water.

Example: calculate heat stored in 528gal Pressurized Storage Heater when the permitted temperature variation Ts-Tm equals to 18 deg F.
Q(a) = 528 x 8.345 x 1 x 18 = 79311 Btu

Atmospheric Hot Water Storage Heaters

Atmospheric Hot Water Storage Heaters have similar design to Pressurized Storage Heaters, but they are open to the atmosphere. This type of storage heater is commonly used in several European countries and is used in the US for cold water storage.

The incoming cold water is heated to the requested temperature at a constant water flow rate, usually, called recovery. The heating section is selected for recovery rate. If water consumption equals the recovery rate, than the level of the stored water remains the same. When the water demand is increased, the level of the stored water is decreased. And when the water demand is decreased, the level of the stored water is again increased.

The incoming water flow rate is constant during the day, while the flow rate of the outgoing water depends on hot water demand during the day. Obviously, the flow rate of outgoing water is equal or larger than flow rate of water entering the vessel. An analysis of water consumption patterns in hotels and other type of dwellings shows that there are three water consumption periods as follows: water accumulating, water discharge and standby.

Water Accumulating

When water demand is lower than hourly water supply, then the level of the stored water is rising. The TRV is open to provide heating of the incoming water to the set temperature. When the maximal level is achieved, the water supply is stopped by the liquid level control, and steam supply is reduced to minimum to compensate the heat losses.

Water Discharging

When water demand is larger than hurly water supply, then the level of the stored water drops. The steam supply remains the same as during the period of water accumulation.

Standby Period

When the stored water is not consumed, then steam consumption will be reduced to compensate the heat loss from the heater and the return pipe. The water flow rate equals to the flow rate of re-circulation.

In conclusion, the method of hot water storage in the Atmospheric vessels is based on:

1. Variable volume of stored water
2. Constant incoming and variable outgoing water flow rate
3. Constant temperature of stored water

Heat, Stored in the Atmospheric Storage Heater:
Q(a) = (Mf-Ma) * Cp * (Ts-Tc) Btu

Where:
Ts-required temperature of the stored water (deg. F)
Tc-the temperature of cold water (deg. F)
Mf=weight of water at maximal level (lbs)
Ma-weight of water at minimal level (lbs)
Cp-specific heat of water

As follows from this equation, the heat stored in the Atmospheric Storage Heater, depends on temperature of the incoming water.

Example: calculate heat stored in the 528gal Atmospheric Storage Heater
Q(a) = 528 x 8,345.1 (140-40) = 440,616 Btu

The Pressurized Storage Heater of the same size stores only 79311 Btu.

Alstrom Hot Water Generator

The Alstrom Corporation introduced a new, patented hot water heater that combines the advantages of instantaneous and storage heaters (Alstrom Hot Water Generator ASH). The Alstrom Hot Water Generator consists of storage section and built-in instantaneous shell and tube heat exchanger. Steam or boiler water passes through the shell. At average recovery period the incoming water enters the tubes of the tube bundle, where it is heated to the required storage temperature. When the water consumption is lower than the recovery rate, the temperature regulator reduces the supply of the heating media in order to prevent the overheating of the stored water. And when the water demand is higher than the recovery rate, the temperature regulator provided the maximal available steam.

The immersed shell serves as an additional heat transfer area. Due to the natural convection, water circulates from the bottom of the tank via tube bundle to the upper part of the storage tank. If the heating section is damaged, the storage tank can be disconnected. The repair or replacement of the heat transfer section can be performed without draining the tank. Hot water already stored in the tank can provide uninterrupted minimal hot water demand (for example, at night).

The heater is constructed from 316L stainless steel storage section and immersed heat exchanger. Many manufacturers of 316L storage tanks provide up to 10 years guarantee against material and workmanship failures.

Alstrom Combinational Hot Water Generator ASH can be sized as a Pressurized or Atmospheric heater.

Sizing of Storage and Compact Heaters

ASHRAE Handbook recommends two different methods of sizing Pressurized Storage and Compact Heaters without offering any analytical backup to their approach. Each offered method yields a very different result when selecting a heater for the same set of data. The oldest practice is to heat total tank volume of incoming cold water to set temperature within one hour. Unfortunately, this method does not take into consideration the actual pattern of heat supply and demand. Many manufacturers of heat transfer equipment recommend their methods with some justification, but they usually recommend ASHRAE methods for government projects.

ASHRAE Fixture for Hot Water Demand (FD) Method

ASHRAE Application Handbook recommends the following data (at a final temperature of 140 deg. F.)

Hot Water Demand per Fixture (gal/hr)

Basin, private lavatory	2
Basin, public lavatory	8
Tub & shower	20
Dishwasher	50-200
Barber basin	12
Beauty parlor basin	12
Kitchen sinks	30
Pantry sinks	10
Service sink	30
Demand factor	0.25
Storage capacity factor	0.8

Example: 200 Room Hotel:

No. Fixtures	Type of Fixture	Maximal Water Demand (gal/hr)
200	Private lavatory	200 x 2 = 400
10	Public lavatory	10 x 8 = 80
20	Private shower	20 x 20 = 400
186	Tub & shower	186 x 20 = 3720
6	Beauty Parlor Basins	6 x 12 = 72
4	Barber basins	4 x 12 =48
Total		4720gal/hr

The heating section should have a water heating capacity (Recovery) equal to Maximal Water Demand multiplied by the Demand Factor. The storage section should have a capacity equal to the Recovery Capacity multiplied by the Storage Capacity Factor.

Recovery capacity	4720 x 0.25 = 1180gal/hr
Maximal daily water capacity per unit	24 x 1180/200 = 141.6gal/day
Storage capacity	1180 x 0.8 = 944 gal
Heat recovery	1180 x 8.345 x 1 (140-40) = 984710Btu/hr
Heat recovery to peak heat demand ratio	984710/3,736,293 = 0.264
Steam rate	995lbs/hr

ASHRAE recovery – Storage Capacity Ratio (RSR) Method

Volume of a storage section depends on recovery rate of the heating section. The higher the recovery rate results in the smaller storage section. 1995 ASHRAE Application Handbook, Chapter 45 provides the relationships between recovery and storage capacity for the various building categories.

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The following data was extracted from the curves of the ASHRAE Handbook; p.45.13, fig 16.

Hotel/Motel	20 units or less	60 units	100 units or more
Usable Storage Capacity per unit (gal)	16 8 2	16 8 2	16 8 2
Recovery Capacity per unit (gph)	1.5 2.8 5	1.25 2.1 3.9	1. 1.4 3.2
Storage/Recovery Ratio(hours)	10.67 2.86 0.4	12.8 3.8 0.51	16 5.71 0.625

The usable storage capacities are net usable requirements. Due to temperature stratification the average temperature of the stored water is lower than the desirable outlet temperature. Assuming that 70% of the hot water in a storage tank is usable, the actual storage tank should be increased by 43% in order to compensate for unusable hot water.

Option 1: Water Recovery Capacity for 200 units:

Maximal daily water capacity per unit	200 x 1 = 200gph
Net storage capacity	24 x 200/200 = 24gph
Actual storage capacity	200 x 16 = 3200gal
Heating section capacity	3200 x 1.43 = 4576gal
Heat recovery to peak heat	200 x 8.345 x 1 x (140-40) = 166900Btu/hr
Demand ratio	166900/3,736,293 =0.0447
Steam rate	169lbs/hr

Option 2: Water Recovery Capacity for 200 units:

Maximal daily water capacity per unit	200 x 1.4 = 280gph
Net storage capacity	24 x 280/200 = 33.6gph
Actual storage capacity	200 x 8 = 1600gal
Heating section capacity	1600 x 1.43 = 2288gal
Heat recovery to peak heat	280 x 8.345 x 1 x (140-40) = 233660Btu/hr
Demand ratio	233660/3736293 = 0.0625
Steam rate	239.6 lbs/hr

Option 3: Water Recovery Capacity for 200 units:

Maximal daily water capacity per unit	200 x 3.2 = 640gph
Net storage capacity	24 x 640/200 = 76.8gph
Actual storage capacity	200 x 2 = 400gal
Heating section capacity	400 x 1.43 = 572gal
Heat recovery to peak heat	640 x 8.345 x (140-40) = 534080Btu/hr
Demand ratio	534080/3736293 = 0.143
Steam rate	530 lbs/hr

Recovery Capacity		RSR Method	FD Method
Maximal daily water capacity	gal/hr	640	1180
Capacity per unit	gal/day	76.8	141.6
Heat recovery	Btu/hr	534080	984710
Steam rate	lbs/hr	530	995
Actual storage capacity	gal	572	944

The comparison of the tabulated data shows that the ASHRAE methods result in significant difference of the storage section size and heat recovery without any explanation.

The previous calculations are based on consumption of 140 deg. F hot water using 40 deg. F cold water to obtain 100 deg. F. mixed water at the fixture. Any variation of these standard temperatures will affect the hot water consumption. The Correction Factor from the following formula should multiply the calculated standard Hot Water Demand: CF = [(Tm-Tc) / (Tm-40)] x [Th-Tc) / (140-40)]

For example, if the heater is sized for 792.0gal/hr recovery and 1321gal storage section, but actual cold-water temperature is 68 deg. F and hot water temperature is 176 dg F, then:

CF = [(100-68) / (100-40)] x [(176-68) / (140-40)] = 0.576

The recovery of hot water at 176 deg F.
792 x 0.576 = 456gal/hr and storage section 1321 x 0.576 =761gal

The Alstrom method of Sizing Hot Water Storage Heaters

The Alstrom method of sizing storage heaters is based on comparison of integrated heat supply and demand during the periods of accumulation and discharge. It utilizes the more general concept of storing energy by heat recovery rather than water recovery.

This method was developed by Russian scientist Dr. Hludov with modifications made by the Alstrom President, Dr. Ari Nir. The similar ideas and useful recommendation are provided by the paper of Valentine A. Lehr, PE, "A Hot Water Requirements for Hotels" in Heating, Piping Air Conditioning Magazine.

The Alstrom method utilizes statistical data of daily hot water consumption per unit. This data may be extracted from ASHRAE handbook, but the most accurate information can be established from the measured hot water demand pattern of comparable buildings.

The Average Hourly Heat Recovery equals:
Q = a * n*Cp (Ts-Tc) /24

Where:
a: hot water demand at maximal day water recovery per one unit gal/day.
n: number of units.

ASHRAE Applications handbook recommends the following Hot Water Demand at maximal day(gal/hotel unit):

Number of units	<=20	60	>=100
ASHRAE Hot Water Demand at maximum day (gal/hotel unit)	35	25	15

The typical pattern of heat demand throughout the 24 hour period is presented by the following table.

Hours	Relative Heat Demand	Relative Hours	Period
0-2	0.8	0.8 * 2 = 1.6	Accumulation
2-7	0.2	0.2 8 5 = 1.0	Accumulation
7-12	2.2	5 * 2.2 = 11	Discharge
12-18	0.8	6 * 0.8 = 4.8	Accumulation
18-22	1.4	4 * 1.4 = 5.6	Discharge
22-24	1.2	2 * 1.2 = 2.4	Discharge
Total		= 26.4	

The ratio of total relative hours to 24 hour period may be called as a Coefficient of Thermal Storage irregularity CTR.
In this case:
CTR = 26.4/24 = 1.1

Example: estimated size of the heaters and heat demand for 200 units hotel with hot water temperature 140 deg. F and cold water temperature 40 deg. F.

Estimated Hourly Heat Demand:
Q(d) = 15 x 8.345 x 1 x (140-40) /24 = 104312Btu/hr

Estimated Hourly Heat recovery:
Q(a) = 104312 x 26.4/24 = 114743Btu/hr

Hours	Relative Heat Demand	Heat Demand	Integrated Heat Demand, Btu	Integrated Heat Supply, Btu	Stored Heat, Btu
0-2	0.8	104312 x 0.8 x 2 = 166,899	166,899	229,341	41,698
2-7	0.2	104312 x 0.2 x 5 = 104,312	271,211	802,694	458,683
7-12	2.2	104312 x 2.2 x 5 = 1,147,432	1,418,643	1,376,048	41,698
12-18	0.8	104312 x 0.8 x 6 = 500,698	1,919,341	2,064,071	145,944
18-22	1.4	104312 x 1.4 x 4 = 584,147	2,503,488	2,522,754	20,849
22-24	1.2	104312 x 1.2 x 2 = 250,348	2,753,837	2,753,837	

Since Total Heat Supply should be equal or greater than Total Heat Demand at any period of the day, the further correction is required until Accumulated Heat becomes positive.

Assume Q(a) = 114743 + (41698/12) = 118219 Btu/hr

Hours	Relative Heat Demand	Integrated Heat Demand, Btu	Integrated Heat Supply, Btu	Stored Heat, Btu	Period
0-2	0.8	166,899	236,286	69,492	Accumulation
2-7	0.2	271,211	827,000	555,960	Accumulation
7-12	2.2	1,418,643	1,417,746	0	Discharge

12-18	0.8	1,919,341	2,126,571	288,444	Accumulation
18-22	1.4	2,503,488	2,599,000	97,095	Discharge
22-24	1.2	2,753,837	2,835,429	83,333	Discharge

Due to heat loss in return pipe the temperature of the hot water at the far end may be 18 deg F., lower than the temperature of water, leaving the heater. In order to keep the average temperature 140 deg. F at the fixture assume the set temperature of the Pressurized storage heater equals 149 deg F.

$$\frac{\text{Maximal Stored Heat}}{149-131} = \frac{555960}{18} = 30887\text{lbs}$$

The size of the storage section can be reduced by using higher set temperature with further tempering of stored water with cold water in the mixing valve. For example, if the set temperature of water is 180 deg. F, then

Net Storage Section Capacity of the Pressurized Vessel equals:

$$\frac{\text{Maximal Stored Heat}}{180-131} = \frac{555960}{49} = 11346\text{lbs}$$

If set temperature of the Atmospheric storage heater equals 149 deg. F then
Net Storage Section Capacity of the Atmospheric Vessel:

$$\frac{\text{Maximal Stored Heat}}{149-68} = \frac{555960}{81} = 6864\text{lbs}$$

The size of the Storage Section can be reduced by using higher set temperature with further tempering of stored water with cold water in the mixing valve.

If set temperature of water is 180 deg. F, then
Net Storage Section Capacity of the Atmospheric Vessel:

$$\frac{\text{Maximal Stored Heat}}{180-68} = \frac{555960}{112} = 4964\text{lbs}$$

These selections provides the size of the storage section for a system with minimal-practically steady steam combustion.

When the space in the boiler room is limited or there is a large source of steam, then a smaller Pressurized Compact Heaters can be used. The selected heating element provides practically constant heat rate, as long as the temperature of the stored water below the set temperature of the TRV.

Indeed, heat exchanged
Q(a) = A x U x LMTD

Where:
Q(a)- heat exchanged (Btu/hr
A- heat transfer area (sq.feet)
U- overall heat transfer coefficient (Btu/sq.feet x hr x deg. F)
LMTD- log mean temperature difference (deg. F)

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For storage and compact heaters heat exchanged depends mostly on the difference between steam temperature and cold water temperature that may be assumed constant during the day. The following heat balance equation can be used:

Q(dm) = M x (Ts -Tm) x Cp + Q(h) x DP or
Q(h) = [Q(dm) – M x (Ts – Tm) x Cp] / DP

Where:
Q(dm)- heat demand during discharge period (Btu)
Q(a)- heat recovery (Btu/hr)
DP- discharge period (hr)
M- weight of the stored water (gal)

For the discussed case, maximal Accumulated Heat during the day equals 555960 Btu. This heat will be discharge within period from 7a.m. to 12 a.m.

Therefore:
Q(d) = 555960 + 118143 x 5 = 1,146,674Btu

In order to compare this method with ASHRAE AARSSR@ Curve Method, the volume of the storage tank is taken from the previous example:

Option 1: Assume Net Storage Section equals 3200 gal
O(h) = (1,146,674 – 3200 x 8.345 x 18) / 5 = 133200Btu/hr

ASHRAE AARSR @ method requires 166900 Btu/hr
In this case, discharge period equals:

DP = (1,146,674 – 3200 x 8.345 x 18) / 166900 = 4 hours or
delta t = (1,146,674 – 166900 x 5) / (3200 x 8.345) = 11.7deg F.

Option 2: Assume Net Storage equals 1600gal
Q(h) = (1,146,674 - 1600 x 8.345 x18) / 5 = 181268Btu/hr

ASHRAE AARSR @ method requires 233660 Btu/hr
In this case, discharge period equals:

DP = (1,146,674 – 1600 x 8.345 x 18) / 233660 = 3.88 hours or
delta t = (1,146,674 - 233660 x 5) / (1600 x 8.345) = 1.62deg F.

Option 3: Assume Net Storage Section equals 400 gal
Q(h) = (1,146,674 - 400 x 8.345 x18) / 5 = 217318Btu/hr

ASHRAE AARSR @ method requires 534080 Btu/hr
In this case, discharge period equals:

DP = (1,146,674 – 400 x 8.345 x 18) / 534080 = 2.03 hours

ASHRAE AFD @ method requires 984710 Btu/hr
In this case, discharge period equals:

DP = (1,146,674 – 400 x 8.345 x 18) / 984710 = 1.1 hours

Selection of heaters described above by The Alstrom Method is based on 5 hours reheat time. Heat demand for other reheat times can be also calculated. The following table shows Heat Recovery as function of the size of Storage Section and Discharge Period.

	Discharge Period (hours)				
Storage Section (gal)	5	4	3	2	1
3200	133200	166500	222000	333000	666000
1600	181268	226585	302113	453170	906340
400	217318	271647	362197	543295	1086590

The calculations show that the sizing of a compact heater and, as result, heat recovery depends on the permitted temperature fluctuation within the storage section and hours of discharge period. There are many options for size selection of the storage heart and, consequently, steam demand.

The pressurized Hot Water Heaters selected by ASHRAE Methods provide quicker reheat time, and obviously, need more available steam. Further decrease of the storage section may result in insufficient storage capacity and drastic increase in steam peak demand.

The A.O. Smith & Company recommends the following minimal storage Capacity for Hot Water Hotel Systems.

Number of Units	Storage Capacity (gal)
10	106
30	158
75	264
150	357
200	423
300 and more	602

Return Piping

Usually, hot water systems for hotels are designed to have hot water available continuously at the fixtures by using return piping. When the designer selects Heat Recovery Section, the amount and temperature of return water should be taken in consideration.

Return Water Flow Rate = Heat Loss / Cp x (Th – Tr)

$$\text{Re-circulation Ratio } R = \frac{\text{Return Water Flow Rate}}{\text{Net Water Flow Rate}}$$

The actual Hot Water Flow Rate via the heater

WFR(h) = Net Water Flow Rate* (1 + R)

The actual Cold Water Temperature entering heater

T(ac) = (Tc + R * Tr) / (1 + R)

The actual Heat Exchanged Capacity

Q(h) = Net Heat Capacity + Net Water Flow Rate * R * Cp * (Th – Tr)

For the previously considered instantaneous heater assume
R = 0.1, Tc = 40 deg. F, Th = 149 deg. F, Tr = 131 deg. F

WFR(a) = 4107.6 * (1 + 0.1) = 4518.4 gph

$$T(ac) = \frac{40 + 0.1 * 131}{1 + 0.1} = 48.3 \text{ deg. F}$$

Q(h) = 3,736,293 + 4107.6 x 8.345 x 0.1 x 1 x (149-131) =3,797,993 Btu/hr or
Q(a) = 4518.4 x 8.345 x 1 x (149 – 48.3) = 3,796,999 Btu/hr

Of Course, similar calculations are valid for storage and compact heaters.
Sizing of heat recovery section without taken into consideration, the amount and temperature of return water results in under sizing of the heater. It also causes increase in pressure drop.

For this example, this increase approximately equals to $\frac{4518.4}{4107.6} \times \frac{4518.4}{4107.6} = 1.21$

Major Problems – Scale Formation, Corrosion & Water Hammer

The common problems that occur in the heat exchanges are: scale formation, corrosion, and water hammer. Indeed, the rate of scaling increase with temperature rise and prolonged usage because calcium carbonate and other solids lose solubility at high temperature from hard water. Scaling results in poor performance of the heater and increased pressure drop. Scaling can be reduced by selecting a heater with high water velocity to generate turbulent flow that prevents the precipitation of scales on the surface. The Alstrom Corporation recommends water velocity in the 5-8 ft/s that may be achieved in the water heaters with a pressure droop of 3 – 7.5 psi.

Corrosion problems increase with temperature because corrosive oxygen and carbon dioxide gases are release from the water. The Alstrom Corporation recommends the use of 316L stainless steel that has superior corrosion resistance. The concentration of chlorides should be maintained at the minimal recommended level in order to prevent stress corrosion.

Steam hammer can cause serious damage to the tubes of any heat exchanger. A vacuum breaker and/or air vent should be used in accordance with the type of steam system installed.

The proper steam trap should be selected for the total capacity of the temperature regulator (not the capacity of heat exchanger!) for the pressure at the trap. A careful consideration of the above-mentioned points, before installation is done, could prevent costly repairs that may be caused by steam hammer. In addition, a properly sized relief valve must be installed on the heated waterside to protect heat exchanges from possible damage due to volumetric expansion.

The weakest point in the heat exchange is tube-to-tube-sheet joints. Tube expansion and further seal welding tubes to the tube-sheet achieve the most efficient joins.

Conclusions

Instantaneous and Semi-instantaneous Heaters require minimal space and very large steam supply. They may be recommended for applications where unlimited or inexpensive steam is available. Self-contained TRV can be used if there are no momentary changes in hot water consumption. Otherwise, pneumatically operated TRV should be used.

Storage heaters require minimal and steady supply of steam, but they have the largest size of storage section as opposed to compact heaters that require smaller size of the storage section, but they need more hourly steam supply. The major factor in sizing of compact heaters is the duration of the discharge period that depends on the type and location of the hotel. Surprisingly, size of the storage section has limited effect on the requested heat recovery. Self-contained TRV provides sufficient temperature control.

In comparison with empirical ASHRAE Methods, The Alstrom Method provides analytical approach for sizing of storage section, steam requirement calculation, and prediction of temperature variations of the mean stored water temperature during the periods of heat accumulation and discharge. All of the discussed methods provide legitimate result that may be considered by a designer, depending on specifics of the particular project.

Atmospheric Hot Water Storage Heaters have minimal sizes and require minimal amount of heat. The usage of these heaters should be considered.

All mentioned above methods can be used for the sizing of storage heaters and boilers. Economical analysis, space limitations, hot water demand for kitchens, laundries, swimming pools, as well as, other factors may affect the decision of the designer to select heaters and boilers.

It should be taken in consideration, that design calculations are based on heating cold water, entering at minimal temperature during the year. In reality, this temperature will be higher during most of the seasons and, consequently, heat demand will be reduced. The TRV will reduce the steam supply and, as a result, boilers and heaters will not be used for their full capacity.

Over sizing of boilers and heaters increases the initial cost of the system, but he under sizing of the heating capacity may result in sever shortage of hot water during the coldest periods of the year. The system's designer shall establish the delicate balance between the investment in the system and its reliability.