COLMAC WATERHEAT

Engineering Bulletin

930091-0053

Heat Pump Water Heater
System Design

Contents

1. INTRODUCTION

1.1. Sanitary (Domestic) hot water can be effectively and efficiently heated using Colmac Heat Pump Water Heaters. Because they use low grade (low temperature) heat as the energy source, Colmac Heat Pump Water Heaters can heat sanitary water and simultaneously cool air (or water) with as little as 1/10th the energy input of conventional boilers and chillers. Correctly piping the Colmac Heat Pump Water Heater to the building hot water system is critical to proper and successful operation. Incorrect piping and/or storage tank selection can result in inadequate hot water temperatures and/or heating capacity of the system - even though the heat pumps may be sized with more than enough heating capacity! See Colmac Engineering Bulletin ENG00018546 for information on proper piping of Colmac Heat Pump Water Heating systems.

2. SANITARY HOT WATER LOAD CALCULATION:

2.1. To properly design a Colmac Heat Pump Water Heater system, an accurate estimate of daily sanitary water heating load for the building must be made.

2.2. New Systems

2.2.1. If the facility is a new building being designed then an estimate of daily hot water usage must be made based on one or more of the following methods:

- ASHRAE HVAC Applications Handbook, Domestic Water Heating Chapter
- EPRI Commercial Water Heating Applications Handbook
- Best Practice based on Local Engineering Experience

2.3. Existing Systems

2.3.1. If the facility is existing, historical monthly natural gas, or electrical power consumption for the sanitary water heating system may be used to estimate the hot water usage. Use Worksheet No. 1 at the end of this Engineering Bulletin to calculate the daily water heating load and daily hot water usage.

2.4. Load Profile

2.4.1. For most sanitary water heating applications, hot water usage varies from hour to hour and follows a “load profile” over the course of the day. Normally in occupied buildings (hotels, apartments, hospitals, restaurants, etc), peaks in hot water usage occur in the morning hours and again in the evening.

2.4.2. Heating and storing hot water during off-peak periods allows the heat pump water heater size (and first cost) to be reduced.

2.4.3. The load profile (hour by hour hot water usage) for the building is important required information for properly sizing storage volume and heat pump heating capacity.

3. HEAT SOURCE AVAILABILITY

3.1. General

3.1.1. Both Colmac HPA air-source and HPW water-source heat pump water heaters require sufficient amounts of waste heat for proper operation of the heat pump system. Provided the quantities of waste heat are equal to or greater than the heat pump cooling capacity year around and at all hours of the day, all of the sanitary water heating for the building or process can be provided by the heat pumps. If this is not the case then a backup water heating system must be included in the design.

3.2. **Air-Source Systems**

3.2.1. Air-source heat pump water heaters can use either outdoor (ambient) air or indoor air as the heat source.

3.2.2. When outdoor air is used as the heat source, standard Colmac heat pump water heaters cannot be operated when ambient air temperatures fall below 50F (10C). Monthly weather data must be checked carefully for the location. As long as ambient air temperatures do fall below 50F (10C), no backup water heating system is needed. Colmac heat pump water heaters fitted with special defrost controls can be operated with ambient air temperatures between 35F (1C) and 48F (9C).

3.2.3. When indoor air is used as the heat source, care must be taken to confirm that the air-conditioning load in the space to be cooled by the heat pump water heaters is greater than or equal to the cooling capacity of the heat pumps. When the cooling capacity of the heat pump water heaters exceeds the air-conditioning load of the space cooled, then the risk of overcooling the space exists and backup water heating must be provided.

3.3. **Water-Source Systems**

3.3.1. Water-source heat pump water heaters typically use building return chilled water or condenser loop water as the heat source. In order for the heat pump water heater system to operate properly, the air-conditioning load must be greater than the heat pump cooling capacity during all months of the year and all hours of the day. In the case where the heat pump water heater cooling capacity exceeds the air-conditioning load, backup water heating must be provided.

4. HOT WATER STORAGE

4.1. **General**

4.1.1. Hot water storage tanks in the Colmac Heat Pump Water Heating system perform an important function. With adequate storage tank volume, the heat pump does not have to be sized like a boiler to produce hot water at peak hot water demand flowrate. Most sanitary water heating applications have some time of the day when the hot water demand is relatively low, this is when the Colmac HPA/W system is “catching up” and storing hot water in the tanks. Increased storage volume improves the ability of the system to meet high peak hot water demands. Generally speaking, bigger is better for storage tanks, however, there is obviously some economic optimum tank size for a given system.

4.1.2. Storage tank volume can be determined a number of ways. The best way is to allow your Colmac representative will select the optimum combination of Colmac heat pumps and storage tank volume based on a number of operating parameters including: daily hot water usage, building load profile, hot water piping volume, etc.

4.1.3. Another important function of storage tanks is the water temperature stratification they provide to the heat pump. Colmac HPA/W heat pumps are provided with their own internal water circulating pump controlled by the proprietary e-TCV control. This feature monitors supply water and tank temperatures and delivers constant safe sanitary hot water temperature leaving the heat pump. This important feature not only delivers safe, hot water at set point temperature during startup and periods of high demand, but also acts to maximize storage efficiency in the tanks. Details on operation and adjustment of the Colmac e-TCV control can be found in Colmac IOM ENG00018008.

4.1.4. NOTE: Colmac recommends that the ringmain loop and supply riser pipe volume be included in the total storage volume for the sanitary hot water system. Taking credit for the loop and supply riser volume allows the hot water tank size to be reduced. This reduces first cost for the tanks and reduces overall weight of the hot water storage system.

4.2. **Storage Tank Efficiency**

4.2.1. To maintain 100% safe sanitary hot water at all times, Colmac recommends that hot water storage tanks always be pressurized, and that they be piped as shown in the diagrams below. Piping hot water storage tanks in series combined with proprietary Colmac e-TCV technology results in hot water storage efficiencies not previously possible.

4.2.2. Unlike other heat pump water heating equipment that requires multiple passes to heat the storage tanks to set point temperature, Colmac HPA/W heat pump water heaters with e-TCV technology heat the sanitary water to set point temperature in a single pass.

4.2.3. During the recharging cycle when hot water usage in the building is low and tanks are being filled with hot water, the Colmac HPA/W heat pump(s) fill the storage tanks “from the top down” with full set point temperature hot water. The heat pumps only cycle off when all of the storage tanks are full of set point hot water to the level of the aquastat, which is typically located at a low elevation in the “cold tank” (the tank supplied by the cold water supply pipe).

4.2.4. Storage tank efficiency in the Colmac piping system is calculated simply as the total storage volume “above” (i.e. between the aquastat location and the top of the hot tank) the level of the aquastat in the tanks divided by the total storage volume.

$$\boldsymbol{Storage\ Efficiency}, \% = \left(\frac{\boldsymbol{Tank\ Volume\ Above\ Aquastat}}{\boldsymbol{Total\ Tank\ Volume}}\right) \times \mathbf{100}$$

4.2.5. Storage tank efficiencies in the Colmac piping system (with multiple vertical tanks) is typically in the range of 85 to 95%.

4.2.6. Total Effective Storage Volume for the Zone is then equal to: Storage Tank Volume x Storage Efficiency + Total Ringmain Loop Volume + Hot Water Supply Riser and Return Pipe Volume

5. RINGMAIN LOOP HEAT LOSS AND FLOWRATE

5.1. **Background**

5.1.1. In buildings where the sanitary water heating equipment is located more than 100 ft (30 m) away from the point of use, ringmain loops (i.e. recirculating loops) are used to insure that the hot water is always delivered to the fixtures at setpoint temperature. Occupants never have to wait for hot water with a properly designed Colmac sanitary water heating system!

5.1.2. Unavoidably, the hot water circulating in the ringmain loses some heat to the surroundings and has to be reheated in order to maintain safe sanitary temperatures in the loop. Ringmains *always* lose some amount of heat which must be accounted for when sizing the water heating equipment. Whereas the fixture water heating load (daily hot water usage) is characterized by the building load profile, the ringmain heating load is continuous and does not vary. These two types of water heating loads are calculated differently and must be handled separately in the piping system.

5.1.3. In larger systems where loop lengths are long and recirculation flow rates are large, storage tanks will be diluted and the desirable tank temperature stratification lost if the recirculation loop flow is improperly routed through the storage tanks. In the case where recirculation loop flow rate matches flow rate through the heat pumps, storage tank temperatures may never reach set point while loop water becomes overheated.

5.1.4. To avoid these problems it is important that the water heating loads for both the fixtures and ringmain loop be calculated carefully, and the piping arranged as shown in Colmac Engineering Bulletin ENG00018546.

5.2. **New Systems**

5.2.1. It is recommended that ringmain (and hot water supply riser) heat loss be calculated according the method presented in the ASHRAE HVAC Applications Handbook. Heat loss from the loop can be significant and should always be calculated. Depending on the length of the loop and whether or not insulation is used, heat loss from the loop may be as high as 20 to 50% of the water heating load calculated for fixtures! Colmac provides software written to calculate ringmain loop heat loss based on the above mentioned ASHRAE Handbook method.

5.2.2. Ringmain flowrate is calculated based on the calculated loop heat loss and the allowable water temperature drop in the loop. This flowrate calculation is also found in the ASHRAE HVAC Applications Handbook.

5.3. **Existing Systems**

5.3.1. An estimate of ringmain loop heat loss in existing systems can be calculated if the loop flowrate can be estimated and the loop water temperature drop measured.

5.3.2. Two methods can be used to estimate the ringmain pump flowrate in existing systems:

- Using the Pump Curve. - If a pump curve is available for the model and speed of the recirculating pump, then the flowrate can be determined by first measuring the head (difference between pump discharge and suction pressure) with a good quality pressure gage, then reading the flowrate directly from the pump curve.

- Based on Pump Power. - If no pump curve is available, the flowrate can be estimated using the following formula (provided the Brake Power of the pump motor can be determined):

  IP

$$Q = \frac{P \times 3960 \times eff}{H \times s.g.}$$

SI

$$Q = \frac{P \times 1000 \times eff}{H \times s.g.}$$

Where:

Q	= pump flowrate, gpm [L/s]
P	= nameplate brake (shaft) power rating of the pump motor, Hp [kW]
H	= measured difference between pump discharge and suction pressure (pump head), ft H2O [kPa]
$s.g.$	= specific gravity of water = 1.0
eff	= pump efficiency (assume 0.35)

Example (IP):

Pump nameplate horsepower: 1/6 Hp
Measured difference between pump discharge and suction pressure (i.e. pump head): 20 ft H2O

Calculated pump flowrate = (0.167 x 3960 x 0.35) / (20 x 1.0) = 11.6 gpm

Example (SI):

Pump nameplate power: 0.124 kW
Measured difference between pump discharge and suction pressure (i.e. pump head): 60 kPa

Calculated pump flowrate = (0.124 x 1000 x 0.35) / (60 x 1.0) = .72 L/s

NOTE: This calculation assumes the pump motor is fully loaded to nameplate amps. If measured motor amps vary significantly from nameplate amps then this method is not recommended.

Once flowrate is estimated and the water temperature drop through the loop is measured, the ringmain loop heat loss can be calculated using the following formula:

IP

$$\dot{q} = Q \times 500 \times \Delta T$$

SI

$$\dot{q} = Q \times 4.178 \times \Delta T$$

Where:

$\dot{q}$	= ringmain loop heat loss, Btu/h [kW]
Q	= loop water flowrate, gpm [L/s]
ΔT	= loop water temperature drop, F [C]

Example (IP):

Estimated ringmain loop flowrate: 11.6 gpm
Measured loop water temperature drop: 10°F

Calculated ringmain loop heat loss = 11.6 x 500 x 10 = 58,000 Btu/h

Example (SI):

Estimated ringmain loop flowrate: 0.72 L/s
Measured loop water temperature drop: 5.56°C

Calculated ringmain loop heat loss = 0.72 x 4.178 x 5.56 = 16.7 kW

6. MINIMIZING RINGMAIN LOOP HEAT LOSS

6.1. To minimize ringmain loop heat loss in new buildings, generously insulate ringmain loop piping. Proper insulation of loop piping is essential for minimizing heat loss. Design (minimize) the loop flowrate to give the largest acceptable water temperature drop based on the calculated loop heat loss. Also, install and use a 24 hour timer to cycle the ringmain loop pump off during unoccupied periods or periods of no hot water demand.

6.2. In existing buildings, a 24 hour timer can be installed to cycle the ringmain loop pump off during unoccupied periods or periods of no hot water demand. Flowrate through the loop can also be throttled down to the minimum flow below which loop water temperatures reach unacceptably low levels for users.

7. FACTORS AFFECTING PERFORMANCE

7.1. Ambient Air Temperature: As the ambient air temperature falls, the heating capacity and efficiency (C.O.P.) HPA heat pump decreases. The practical lower limit for ambient temperature is between 50° and 55° F.

7.2. Source Water Temperature: As the source water temperature falls, the heating capacity and efficiency (C.O.P.) HPA heat pump decreases. The practical lower limit for source water temperature is between 50° and 55° F.

7.3. 50 Hz Electrical Power: HPA heat pumps are designed to operate on either 50 or 60Hz power. Capacity with 50Hz will be lower than with 60Hz and is shown in the literature.

8. COEFFICIENT OF PERFORMANCE ("COP")

8.1. The energy efficiency of a Heat Pump Water Heating system is normally quantified by calculating the Coefficient of Performance, or COP. The COP is simply defined as the ratio of useful energy output divided by energy input.

8.2. When sanitary water heating only is utilized, COP is calculated as "Heating COP". When both the sanitary water heating and the cooling effect produced by the heat pump are utilized as useful output, then COP is calculated as "Integrated COP" according to the formulas shown below.

$$\textit{Heating } C.O.P. = \frac{\textit{Heating Capacity}, kW}{\textit{Input } kW}$$

$$\textit{Integrated } C.O.P. = \frac{\textit{Heating Capacity} + \textit{Cooling Capacity}, kW}{\textit{Input } kW}$$

8.3. Colmac Heat Pump Water Heaters typically operate with Heating COP between 3.0 and 5.0. When both water heating and cooling is utilized, Colmac Heat Pump Water Heaters typically operate with Integrated COP in excess of 10.0!

8.4. Electrical resistance water heating equipment typically has Heating COP between 0.85 and 0.95, while natural gas Heating COP is normally only 0.50 and 0.75.

8.5. This substantial "efficiency advantage" when using Colmac HPA heat pumps means a good economic return by reducing energy operating costs and a good environmental return by conserving fossil fuels, and reducing the threat of Global Warming.

9. RECOVERY RATE

9.1. A convenient method of rating water heating heat pump capacity is by Recovery Rate. This rate indicates the capacity of the heat pump to raise the water from supply temperature to finished temperature. Use the following equation to calculate recovery rate.

$$\textit{Recovery Rate}, {}^{gal}/_{h} = \frac{\textit{BTUH Heating Capacity}}{8.33 \times \textit{Water Temperature Rise}}$$

$$\textit{Recovery Rate}, {}^{L}/_{s} = \frac{\textit{kW Heating Capacity}}{4.179 \times \textit{Water Temperature Rise}}$$

Where,

$\boldsymbol{BTUH\ (kW)}$ = output of the heat pump, BTUH (kW)
$\boldsymbol{Water\ Temperature\ Rise}$ = Tank Temperature – Supply Water Temperature, °F (°C)

(Note that Supply Water Temperature varies with location. Typical values for Hawaii are 60° to 70° F (15° to 21° C).

10. SYSTEM DESIGN

10.1. The following procedure is recommended for designing Colmac Heat Pump Water Heating systems in buildings having multiple floors. Use this procedure for each sanitary hot water zone:

10.1.1. Calculate Ringmain Loop heat loss per floor.

10.1.2. Calculate Ringmain Loop volume per floor.

10.1.3. Determine number of floors per Ringmain Loop by dividing the heating capacity of the Colmac HRH (or RH) Ringmain Heater by the heat loss per floor. Maximum number of floors per Ringmain Loop should not exceed 10 floors to avoid excessive water pressure at the fixtures on the lowest floor in the Ringmain Loop. Calculated heat loss for the Ringmain Loop should be slightly less than the heating capacity of the HRH (or RH) unit.

10.1.4. Determine the number of Ringmain Loops in the Hot Water Zone by dividing the number of floors in the Zone by a reasonable number of floors per Ringmain Loop.

10.1.5. Calculate hot water supply riser (and riser return pipe) heat loss.

10.1.6. Calculate hot water supply riser volume (include the volume for the riser return pipe).

10.1.7. Determine the type and number (one per Ringmain Loop plus one for the hot water supply riser) of Ringmain Heaters – Colmac HRH or RH units, in the Zone based on the heat source available.

10.1.8. Calculate the Total Effective Storage Volume for the Zone including Ringmain Loops, hot water supply riser and return pipe, and storage tanks.

10.1.9. Calculate the Daily Hot Water Usage for the Zone.

10.1.10. Determine the Load Profile for the building.

10.1.11. Calculate the required Recovery Rate and Heat Pump water heating capacity based on Daily Hot Water Usage, Load Profile, and Total Effective Storage Volume.

10.1.12. Select Colmac Heat Pump Water Heating equipment based on required heating capacity, type of heat source, operating temperatures, and mechanical room/space configuration.

10.1.13. Confirm that adequate source air or water temperature is available at all times for proper heat pump operation.

10.1.14. For water-source and indoor air-source installations, confirm that the air-conditioning load is equal to or greater to the total heat pump cooling capacity (water heating heat pumps plus ringmain heating heat pumps).

Colmac Heat Pump Water Heaters
Calculation Worksheet No. 1 (IP)
Converting Energy Consumption (Utility Records) to gal/day

I. Calculate Daily Water Heating Load (based on utility records)

$$\boldsymbol{Heating\ Load} = \frac{\boldsymbol{Energy\ Consumption} \times \boldsymbol{Factor} \times \boldsymbol{Efficiency}}{\boldsymbol{30.4}\, {}^{\boldsymbol{days}}/_{\boldsymbol{mo}}}$$

a. Natural or Synthetic Gas:

Heating Load = _____________Therms/mo. x 100,000 x _____Eff. / 30.4 days/mo.

= ______________BTU/day

Note: Efficiency is gas heater efficiency, typically about 0.95

b. Electrical Resistance:

Heating Load = _____________kW-h/mo. x 3413 _____Eff. / 30.4 days/mo.

= _____________BTU/day

Note: Efficiency is electric resistance heater efficiency, typically about 0.95

c. LPG (Liquid Propane Gas):

Heating Load = _____________gal LPG/mo. x 91500 x _____Eff. / 30.4 days/mo.

= _____________BTU/day

Note: Efficiency is propane heater efficiency, typically about 0.65

d. Fuel Oil (#2):

Heating Load = _____________gal oil/mo. x 144250 x _____Eff. / 30.4 days/mo

= _____________BTU/day

Note: Efficiency is oil fire boiler efficiency, typically about 0.65

II. Calculate Daily Water Usage (gal/day)

$$\boldsymbol{Water\ Usage} = \frac{\boldsymbol{Heating\ Load}}{\boldsymbol{Factor} \times (\boldsymbol{Tank\ Temperature} - \boldsymbol{Supply\ Temperature})}$$

Water Usage = _____________BTU/day / (8.33 x (_____°F - _____°F))

= _____________gal/day

Colmac Heat Pump Water Heaters
Calculation Worksheet No. 1 (SI)
Converting Energy Consumption (Utility Records) to L/day

I. Calculate Daily Water Heating Load (based on utility records)

$$\boldsymbol{Heating\ Load} = \frac{\boldsymbol{Energy\ Consumption \times Factor \times Efficiency}}{\boldsymbol{30.4\ {}^{days}/_{mo}}}$$

a. Natural or Synthetic Gas:

Heating Load = ____________MJ/mo. x 0.28 x _____Eff. / 30.4 days/mo.

= _____________kW-h/day

Note: Efficiency is gas heater efficiency, typically about 0.95

b. Electrical Resistance:

Heating Load = ____________kW-h/mo. x _____Eff. / 30.4 days/mo.

= ____________kW-h/day

Note: Efficiency is electric resistance heater efficiency, typically about 0.95

c. LPG (Liquid Propane Gas):

Heating Load = ____________Liters LPG/mo. x 7.083 x _____Eff. / 30.4 days/mo.

= ____________kW-h/day

Note: Efficiency is propane heater efficiency, typically about 0.65

d. Fuel Oil (#2):

Heating Load = ____________Liters oil/mo. x 11.17 x _____Eff. / 30.4 days/mo

= ____________kW-h/day

Note: Efficiency is oil fire boiler efficiency, typically about 0.65

II. Calculate Daily Water Usage (gal/day)

$$\boldsymbol{Water\ Usage} = \frac{\boldsymbol{Heating\ Load}}{\boldsymbol{Factor \times (Tank\ Temperature - Supply\ Temperature)}}$$

Water Usage = ____________kW-h/day / (0.00116 x (_____°C - _____°C))

= ____________L/day

WWW.COLMACWATERHEAT.COM

Colmac reserves the right to change product design and specifications without notice.

For more information on Colmac products call us at 1-800-926-5622 or visit us online at:

WWW.COLMACWATERHEAT.COM