DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
CEMP-ET Washington, DC 20314-1000 ETL 1110-3-489

Technical Letter
No. 1110-3-489 3 April 1998

Engineering and Design
DOMESTIC WATER HEATERS FOR BARRACKS

Distribution Restriction Statement

Approved for public release; distribution is unlimited.

CEMP-ET	DEPARTMENT OF THE ARMY U.S. Army Corps of Engineers Washington, D.C. 20314-1000	ETL 1110-3-489

Technical Letter
No. 1110-3-489 3 April 1998

Engineering and Design
DOMESTIC WATER HEATERS FOR BARRACKS

1. Purpose. This letter provides basic design guidance for the sizing of domestic water heaters for barracks buildings.

2. Applicability. This letter applies to all HQUSACE elements and USACE Commands having military construction and design responsibility.

3. Reference. None

4. Distribution. Approved for public release; distribution is unlimited.

5. Background. There have been questions regarding the sizing for domestic water heaters for barracks. Designers have often used ASHRAE design criteria for motels or dormitories with some over sizing. However the peak demand for domestic hot water in barracks is significantly larger than motels or dormitories due to the concentrated shower pattern of the occupants. This ETL provides a uniform approach to determine domestic water heating requirements for barracks.

6. Guidance.

(a) General

(1) As with any domestic water heating system, storage tank temperature should be maintained at a minimum of 60°C (140°F) to reduce the potential for Legionella Pneumophila (Legionnaire's Disease). Note that higher storage temperatures will result in a lower recovery rate to satisfy the peak demand. Include a cross connection with a mixing valve between the domestic water supply and hot water supply lines (leaving the storage tank) to limit the temperature of water distributed to plumbing fixtures to 43°C (110°F). Require a strainer upstream of the thermostatic mixing valve on both the hot and cold water connections to protect the small orifice in the mixing valve from debris that may be in either line.

(2) If a backflow preventer is installed in the domestic water main entering a building or in the line supplying the domestic hot water system, include provisions to accommodate thermal expansion. In barracks this can be critical as occupants often shower at the same time and after this peak usage event, the hot water loop will be at a relatively low

temperature. During the subsequent recovery phase the water temperature will rise causing the water to expand. If little hot water is being used, this expansion will cause a pressure increase that may activate a relief valve or rupture the storage tank.
The best method to alleviate this excess pressure is to install an expansion tank, sized in accordance with Chapter 12 of the 1996 ASHRAE Systems and Equipment handbook.

(3) Normally if a central energy plant is available it will be life cycle cost effective (an analysis must be performed) to generate domestic hot water using distributed media as the heat source. If there is no central plant or if the plant does not operate during the non-heating season provide a separate domestic hot water source. If the site consists of several barracks buildings, evaluate the life cycle cost of these alternatives:

(a) A single boiler to provide low temperature hot water, 94°C (200°F) to heat exchangers in each barracks for domestic hot water generation.

(b) A single heating source for domestic hot water in each individual barracks separately.

If the barracks building is not part of a building complex and there is no central plant or distribution system available then a single heating source must be provided.

b. Calculations: The following information applies to all types of domestic water heating systems for barracks.

(1) Peak Demand: Design for the case where all occupants are taking showers at essentially the same time. Public law limits the maximum flow from of each shower head and lavatory faucet to 0.16 Lps (2.5 gpm). It is assumed during peak demand that the shower requires 7.5 minutes and the lavatory requires 2 minutes of full hot water flow. As a result, the peak domestic hot water demand can be found using equation (1) below:

$$V_p = (h)(occ)(P)\left(\frac{T_d}{T_s}\right) \qquad (1)$$

where:

V_p = volume of domestic hot water required at peak, L (gal).
h = number of shower heads, ea.
occ = number of occupants using each shower, ea.
T_d = temperature of water delivered to shower valve = 43°C (110°F)
T_s = temperature of water in storage tank, degrees C (degrees F)
P = amount of water used per occupant during peak demand, 90 L/occupant (23.75 gal/occupant)

Note that there is no diversity in the number of occupants in the building. The peak volume of domestic hot water is calculated assuming 100% building occupancy. Also note that equation (1) does not take laundry or dining facilities into account. Add additional hot water requirements if laundry or dining facilities will be requiring hot water during the peak demand period.

(2) Tank Size: Once the peak demand is known, the tank capacity and corresponding recovery rate can be determined. Since space in the mechanical room is frequently limited, select the desired tank capacity first. An initial estimate of tank size can be determined by using 50 L per occupant (12.5 gal per occupant). Normally a selection of 50 L (12.5 gal) will provide acceptable operation at a reasonable cost but it should be noted that other factors including larger tank sizes and higher storage temperatures will reduce amount of recovery required. Larger tank sizes and increased storage temperatures will also result in greater heat loss from the storage tank. Compare selected tank size to standard tank capacities available commercially and with the space available in the mechanical room.

(3) Recovery Rate: Once the tank capacity is known, the recovery rate can be calculated. The recovery rate is the quantity of water to be heated from the inlet temperature to the desired storage temperature. The difference between the inlet water temperature and the water storage temperature is often assumed to be 55°C (100°F). However, this temperature difference should be coordinated with local conditions and revised as necessary. Equation (2) below is used to determine the required recovery rate:

$$R = \frac{V_p - (M\ S_t)}{d} \qquad (2)$$

where:

R = recovery rate at the required temperature, Lps, (gph).
M = ratio of usable water to storage tank capacity (60 - 80%)
S_t = storage tank capacity, L (gal).
d = duration of the peak, (seconds) = $\frac{9.5\ \text{min}}{occupant}\ occ\ \frac{60\ \text{sec}}{\text{min}}$ (SI)
d = duration of the peak, (hours) = $\frac{\frac{9.5\ \text{min}}{occupant}\ occ}{60\frac{\text{min}}{hr}}$ (IP)

The duration is calculated assuming that the peak usage period will be 9.5 minutes per occupant. Therefore, if two occupants share a bathroom the duration is 19 minutes, 3 occupants would be 28.5 minutes, etc.

Note that the recovery rate is an output condition. Insure that manufacturer’s data, submitted for the hot water generation unit, indicates that sufficient input capacity to satisfy the recovery rate with actual inlet water and storage temperatures will be provided.

(4) Pipe Sizes: The next component to be sized in the system is the domestic hot water distribution piping. Appendix A of the 1997 National Standard Plumbing Code, Chapter 45 of the 1995 ASHRAE Applications Handbook and Chapter 33 of the 1997 ASHRAE Fundamentals Handbook provide an ample set of resources on this topic. Therefore, this letter will not discuss this process.

(5) Domestic Hot Water Circulation Pump: After the domestic hot water distribution piping has been sized, the domestic hot water circulation pump can be sized. This pump is used to circulate the domestic hot water through the distribution piping system. Size the pump using equation (3) below:

$$Q_p = \frac{q}{c\ r\ c_p\ \Delta T} \qquad (3)$$

where:

Q_p = pump capacity, Lps (gpm)
q = heat loss in the piping system, kW (BTUH)
c = constant, $1\frac{kW \cdot \sec}{kJ}$ $(60\frac{\min}{hr})$
ρ = density of water, $0.9971\frac{kg}{L}$ $(8.33\frac{lb}{gal})$
c_p = specific heat of water, $4.18\frac{kJ}{kg \cdot K}$ $(1\frac{BTU}{lb \cdot °F})$
ΔT = allowable temperature drop through the system, K (°F)

Equation (3) can be simplified to :

$$Q_p = \frac{q}{4.1679\left(\frac{kW \cdot \sec}{L \cdot K}\right)\Delta T} \qquad (4 - SI)$$

$$Q_p = \frac{q}{500\left(\frac{BTUH}{gpm \cdot °F}\right)\Delta T} \qquad (4-IP)$$

Heat loss in the piping system (q) can be calculated using Table 2 in Chapter 45 of the 1995 ASHRAE Applications Handbook. However, a common rule of thumb is 0.032 kW/m (30 BTUH/ft.).

The allowable temperature drop through the piping system (ΔT) is usually 2 to 5K (5 to 10°F). It is recommended to use 2K (5°F) to assure that sufficient hot water is provided for all occupants under peak conditions. If the temperature drop through the piping system will result in a temperature less than 40°C (105°F) at the most remote fixture, require the supply water temperature leaving the mixing valve to be above 43°C (110°F) and revise the storage tank and recovery capacities accordingly.

c. Systems using a separate hot water generation unit and storage tank: The following information applies to systems using a separate storage tank and forced circulation type water heater, boiler or heat exchanger to generate and store domestic hot water. A forced circulation type water heater is similar to a boiler in that it is designed to heat domestic water as it passes through a series of coils rather than heating water in a storage tank but is designed for generating domestic hot water only.

(1) Locate the storage tank and hot water generation unit in the same mechanical room whenever possible. This keeps the head requirements at a minimum for the pump circulating water between the hot water generation unit and the storage tank.

(2) Require the domestic water supply be connected in the line supplying hot water to the storage tank. This allows the cold water to mix with the warmer water in the storage tank before entering the boiler, minimizing problems associated with condensation and thermal stress and improving overall system efficiency. Require a submittal from the manufacturer addressing whether a thermostatically controlled bypass line between the boiler supply and return lines or other means are needed to preclude the possibility of thermal shock to the boiler.

(3) If a forced circulation type water heater or boiler is used, equation (3) again can be used to size the circulation pump between the heater and the storage tank. In this case limit the temperature differential to no greater than 16K (30°F) to minimize problems with condensation and thermal stress and improve overall system efficiency. Also note that the sizing of the circulation pump must account for the heating of the domestic cold water being provided. Therefore, the value of q required to use equation (3) is found with equation (5):

$$q = q_{pipe} + \left(R\ c\ r\quad c_p\ \Delta T_t \right) \qquad (5)$$

where:

q_{pipe} = heat loss in the piping between the boiler and the storage tank, kW (BTUH)
ΔT_t = temperature difference between the tank water and the make-up water, K (°F)

Determine actual storage tank and domestic water supply temperatures based on local requirements. If the water in the tank is assumed to be 60°C (140°F) and the make-up water is 4°C (40°F, equation (5) can be simplified to:

$$q = q_{pipe} + \left(R \times 233.402 \left(\frac{kW \cdot \sec}{L} \right) \right) \qquad (5\text{-SI})$$

$$q = q_{pipe} + \left(R \times 50{,}000 \left(\frac{BTUH}{gpm} \right) \right) \quad \text{(5-IP)}$$

The new value of q can then be inserted into equation (3) to determine the required flow rate for the pump. Compare this flow rate with the minimum flow rates required for boiler or water heater operation and require the larger of the two values. Once the required flow rate is known, the pressure drop for the circulation pump can be determined. The resources listed in paragraph 6.b(4) (Pipe Sizes) give adequate information on calculating the pressure drop through the piping. However, several manufacturers should be contacted to determine the pressure drop through the water heater or boiler. This value will vary widely between different manufacturers. Therefore, the circulation pump should be sized to overcome the highest pressure drop. However, flow rates over or under those required by the boiler or water heater manufacturer can reduce the efficiency of the unit. As a result, the drawings should indicate the pump characteristics used for the design. Then add a note indicating that the pump is to be sized by the boiler or water heater manufacturer with the horsepower requirements not to exceed those listed in the schedule.

(4) If a heat exchanger is used, size the circulation pump based on the flow required for the heat exchanger to meet the recovery calculated in equation (3) and the heat lost through the piping.

d. Sample Computations:

(1) Given:

h = 36 shower heads
occ = 2 occupants per shower
T_d = 43°C (110°F)
T_s = 60°C (140°F)
M = 75% useable tank capacity
ΔT = 5K (9°F) Maximum temperature drop through distribution system.
ΔT_t = 54K (97°F)
Piping system consists of:
9 meters of 50 mm pipe
6 meters of 25 mm pipe
15 meters of 20 mm pipe
A separate tank and hot water boiler will be used.
q_{pipe} = 0.10 kW = 341.18 BTUH

(2) Find:

(a) Peak domestic hot water demand, L (gal).
(b) Storage tank size, L (gal).
(c) Recovery rate required given the tank size selected, Lps (gph).
(d) Flow rate required for domestic hot water circulation pump.
(e) Flow rate required for boiler circulation pump.

(3) Solution:

(a) Peak Domestic Hot Water Demand:

$$V_p = h\ occ \left(\frac{90}{occupant}\right)\left(\frac{T_d}{T_s}\right)$$

$$V_p = (36 heads)\left(\frac{2\ occupants}{head}\right)\left(\frac{90\ L}{occupant}\right)\left(\frac{43^\circ C}{60^\circ C}\right)$$

$$Vp = 4644\ L\ (1227\ gal)$$

(b) Storage Tank Size:

$$S_t = (36\ heads)\left(\frac{2\ occupants}{head}\right)\left(\frac{50\ L}{occupant}\right)$$

$$S_t = 3{,}600\ L\ (951\ gal)$$

Use 2 tanks of 1893 L (500 gal) each to fit into the available space.

(c) Recovery Rate:

$$d = \left(\frac{9.5 \min}{occupant}\right)(2\ occupants)\left(\frac{60 \sec}{\min}\right) = 1140 \sec\ (0.32\ hours)$$

$$R = \frac{4644\ L - (75\% \times 2\ each \times 1{,}893\ L)}{1140 \sec} = 1.58\ Lps\ (1505\ gph)$$

(d) Flow rate for circulation pump (heat loss through piping is 0.629 kW):

$$Qp = \frac{0.629\ kW}{\left(4.1679\ \frac{kW \cdot \sec}{L \cdot K}\right) 5K} = 0.0302\ Lps\ (0.48\ gpm)$$

(e) Flow rate for boiler circulation pump:

$$q = qpipe + \left(R \times 233.402 \, \frac{kW \cdot \sec}{L} \right)$$

$$q = 0.1 \, kW + \left(1.58 \, \frac{L}{\sec} \times 233.402 \, \frac{kW \cdot \sec}{L} \right) = 368.875 kW$$

$$Qp = \frac{368.875 \, kW}{4.1679 \, \frac{kW \cdot \sec}{L \cdot K} \times 16 \, K} = 5.53 \, Lps \; (87.6 \, gpm)$$

7. Action. The guidance included in this technical letter will be used for the planning, design and construction of new and renovated facilities.

8. Implementation. This letter will have routine application, as defined in paragraph 8c, ER 1110-345-100.

FOR THE COMMANDER:

KISUK CHEUNG, P.E.
Chief, Engineering and
Construction Division
Directorate of Military Programs