Residential ACM Appendix E

RACM Appendix E – Water Heating Calculation Method

RACM RG - Water Heating Calculation Method

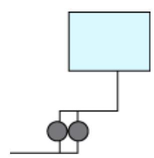
E1 Purpose and Scope

ACM RG documents the methods and assumptions used for calculating the hourly energy use for residential water heating systems for both the proposed design and the standard design. The hourly fuel and electricity energy use for water heating will be combined with hourly space heating and cooling energy use to come up with the hourly total fuel and electricity energy use to be factored by the hourly TDV energy multiplier. The calculation procedure applies to low-rise single family, low-rise multi-family, and high-rise residential.

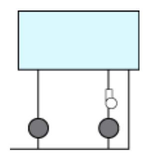
When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

The following diagrams illustrate ~~some of the cases that are~~ the DHW system types that shall be recognized by ~~ACM~~ the compliance software.

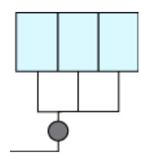
1 One distribution system with ~~two~~ one or multiple water heaters serving a single dwelling unit.



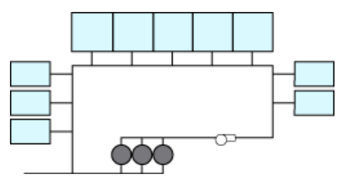
2 Two distribution systems, each with a single water heater serving a single dwelling unit.



3 One distribution system without recirculation loop and with one or multiple water heaters serving multiple dwelling units.



4 One ~~Single~~ distribution system with one or multiple recirculation loops and with one or multiple water heaters serving multiple units.



For multi-family buildings with more than six units, the compliance software shall use system type 4.

The following rules apply to the calculation of water heating system energy use:

- One water heater type per system, e.g. no mix of gas and electric water heaters in the same system
- One solar credit per system.
- Any gas fired system using a temperature buffering storage tank that is electric heating must use the distribution factor for temperature buffering storage tanks provided in Table RE 2.

E2 Water Heating Systems

Water heating distribution systems may serve more than one dwelling unit and may have more than one piece of water heating equipment. The energy used by a water heating system is calculated as the sum of the energy used by each individual water heater in the system. Energy used for the whole building is calculated as the sum of the energy used by each of the water heating systems. To delineate different water heating elements several indices are used.

i Used to describe an individual dwelling unit. For instance CFAi would be the conditioned floor area of the i^{th} dwelling unit. "N" is the total number of dwelling units.

j Used to refer to the number of water heaters in a system. "M" is the total number of water heaters.

k Used to refer to a water heating system or distribution system. A building can have more than one system and each system can have more than one water heater.

l Used to refer to the l^{th} unfired- or indirectly-fired storage tank in the k^{th} system. "L" is the total number of unfired- or indirectly-fired storage tanks in the k^{th} system. Temperature buffering tanks with electric heating shall not to be treated as unfired or indirectly-fired storage tanks.

E3 Hourly Adjusted Recovery Load

The hourly adjusted recovery load (HARL) can be calculated by Equation RE-1~~Equation RE-1~~ through Equation RE-~~7~~6.

Equation RE-1

$$HARL_k = HSEU_k \times DLM_k - HSEU_k \times SSF_k \times SSM_k + HRDL_k + \sum_l HJL$$

Where:

$HARL_k$ = Hourly adjusted recovery load (Btu).

$HSEU_k$ = Hourly standard end use (Btu). See equation RE-2

DLM_k = Distribution loss multiplier (unitless). See equation RE-4

SSF~~M~~$_k$ = ~~Solar Savings Multiplier (unitless) See equation RE-7~~ Solar savings fraction (unitless) for the k^{th} water heating system, which is the fraction of the total water heating load that is provided by solar hot water heating. The value for SSF is provided from the results generated by the CEC approved calculations approaches for the OG-100 and OG-300 test procedure.

$HRDL_k$ = Hourly recirculation loop and branch pipe distribution loss (Btu) See equation RE-10~~1~~.

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system (Btu) See equation RE-28

Equation RE-1 calculates the hourly adjusted recovery load (HARL) which is the heat content of the water delivered at the fixture. HRDL only occurs for multi-family central water heating systems and is zero for single family dwellings.

Equation RE-2

$$HSEU_k = 8.345 \times GPH_k \times \Delta T$$

Where:

$HSEU_k$ = Hourly standard end use (Btu).

GPH_k = Hourly hot water consumption (gallons)

ΔT = Temperature difference (ºF) See equation RE-3

Equation RE-2 calculates the hourly standard end use (HSEU) for each hour at all fixtures. The heat content of the water delivered at the fixture is the draw volume in gallons (GPH) times the temperature rise ΔT (difference between the cold water inlet temperature and the hot water supply temperature) times the heat required to elevate a gallon of water 1ºF (the 8.345 constant). GPH are calculated in a manner consistent with the Standard Recovery Load values in the current water heating methodology).

Equation RE-3
$$\Delta T = T_s - T_{inlet}$$

Where:

ΔT = Temperature difference between the cold water inlet and the hot water supply (ºF)

T_s = Hot water supply temperature of ~~135ºF~~(ºF). For DHW system type 1, 2, and 3, use 135 ºF.. For DHW system type 4, see table RE-4.

T_{inlet} = The cold water inlet temperature (ºF) provided in Table RE3.3 Cold Water Inlet Temperature.

Equation RE-3 calculates the temperature difference (ºF) between cold water inlet temperature T_{inlet} and the hot water supply temperature T_s.

Equation RE-4
$$DLM_k = 1 + (SDLM_k - 1) \times DSM_k$$

Where:

DLM_k = Distribution loss multiplier (unitless)

$SDLM_k$ = Standard distribution loss multiplier (unitless). See equation RE-4 or RE-5

DSM_k = Distribution system multiplier (unitless)Equation RE-4 calculates the distribution loss multiplier (DLM) which combines two terms: the standard distribution loss multiplier (SDLM), which depends on the size of the dwelling unit and the number of stories, and the distribution system multiplier (DSM) listed in Table RE-2.

Equation RE-5
$$SDLM_k = 1.064 + 0.000084 \times CFA_k$$

Where:

$SDLM_k$ = Standard distribution loss multiplier (unitless).

0.0000084 = loss per square foot (1/sq.ft.)

CFA_k = Conditioned floor area (ft^2) capped at 2500 ft^2 for all single and multi-family units.

Equation RE-5 calculates the standard distribution loss multiplier (SDLM) for one story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). Multi-family SDLM's will be calculated based on the one story equation and the average CFA for all units. CFA_k is capped at 2500 ft^2 for all single and multi-family units.

Equation RE-6
$$SDLM_k = 1.023 + 0.000056 \times CFA_k$$

Where

$SDLM_k$ = Standard distribution loss multiplier (unitless).

0.000056 = loss per square foot (1/sq.ft.)

CFA_k = Conditioned floor area (ft[2]) capped at 2500 ft[2] for all single and multi-family units.

Equation RE-6 calculates the standard distribution loss multiplier (SDLM) for two and three story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). CFA_k is capped at 2500 ft[2] for all single and multi-family units.

~~Equation RE-7~~ $$SSM_k = 1 - SSF_k$$

~~Where~~

~~SSM_k = the solar savings multiplier (unitless) for the k[th] water heating system~~

~~Equation RE-7 determines the amount of the total water heating budget that is not provided by solar hot water heating. The value for SSF is provided from the results generated by the solar water heating calculations approved approaches for the OG-100 and OG-300 test procedure.~~

$HARL_k$ = Hourly adjusted recovery load (Btu).

$HSEU_k$ = Hourly standard end use (Btu). This is the amount of heat delivered at the hot water fixtures relative to the cold water inlet temperature.

$HRDL_k$ = Hourly recirculation distribution loss (Btu) is the hot water energy loss in multi-family central water heating recirculation systems (See E4 Hourly Recirculation Distribution Loss for Central Water Heating Systems).HRDL is zero for all single family water heating systems and for multi-family systems with individual water heaters.

DLM_k = Distribution loss multiplier (unitless).

GPH_k = Hourly hot water consumption (gallons) of the k[th] system provided in E3.1 Hourly Hot Water Consumption (GPH).

T_s = Hot water supply temperature of ~~135ºF~~. For DHW system type 1, 2, and 3, use 135 ºF. For DHW system type 4, se table RE-4

T_{inlet} = The cold water inlet temperature (ºF) provided in E3.3 Cold Water Inlet Temperature.

$SDLM_k$ = Standard distribution loss multiplier (unitless). This is calculated using Equation RE-5 for single story dwelling units and from Equation RE-6 for dwelling units with two or more stories. All multi-family projects utilize Equation RE-5 and the average dwelling unit CFA.

DSM_k = Distribution system multiplier (unitless) provided in E3.2 Distribution System Multiplier (DSM) within the Dwelling Unit.

CFA_k = Conditioned floor area (ft[2]) capped at 2500 ft[2] for all single and multi-family units.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater. The HARL for the j[th] water heater is then shown in the following equation.

Equation RE-~~8~~7 $$HARL_j = \frac{HARL_k + \sum_{l=1}^{L} HJL_l}{NmbrWH_k}$$

where

$HARL_f$ = Hourly adjusted recovery load for the j^{th} water heater of the k^{th} system (Btu).

$HARL_k$ = Hourly adjusted total recovery load for the k^{th} system (Btu)

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system (Btu)

L = The total number of unfired tanks in the k^{th} system

$NmbrWH_k$ = The number of water heaters in the k^{th} system.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater. The HARL for the j^{th} water heater is then shown in the following equation.

E3.1 Hourly Hot Water Consumption (GPH)

The average daily hot water consumption GPD for a dwelling unit is equal to 21.5 gallons/day plus an additional 14 gallons per day for each 1000 ft² of conditioned floor area. Consumption is about 31.3 gallons/day for a 700 ft² apartment and 56.5 gallons/day for a 2500 ft² dwelling unit. The equation for daily hot water consumption can be expressed as follows:

Equation RE-~~9~~8

$$GPD_i = 21.5 + 0.014 \times CFA_i$$

where

GPD_i = Average daily hot water consumption (gallons) of the i^{th} dwelling unit.

CFA_i = Conditioned floor area (ft²) of the i^{th} dwelling unit. When actual conditioned floor area is greater than 2500 ft², 2500 should be used in the above equation.

The hourly water consumption GPH of the k^{th} system is calculated using the average daily hot water consumption and the hourly water consumption schedule for all dwelling units served by the system.

Equation RE-~~10~~9

$$GPH_k = \left(\sum_i GPD_i\right) \times SCH_m$$

where

GPH_k = Hourly hot water consumption (gallons) of the k^{th} system.

SCH_m = Fractional daily load for hour “m” from Table RE-1.

m = Hour of the day.

There are significant variations between hot water usage on weekdays and weekends, and separate schedules are used. The hourly schedules shown in Table RE-1 shall be used for calculating the hourly hot water consumption. These data are used for dwelling units of all types.

Table RE-1 Hourly Water Heating Schedules

Hour	Weekday	Weekend
1	0.014	0.018
2	0.008	0.010
3	0.009	0.009
4	0.011	0.008
5	0.020	0.015
6	0.044	0.023
7	0.089	0.026
8	0.107	0.047
9	0.089	0.077
10	0.066	0.083
11	0.052	0.074
12	0.038	0.061
13	0.036	0.051
14	0.033	0.043
15	0.032	0.039
16	0.026	0.039
17	0.042	0.052
18	0.048	0.058
19	0.052	0.056
20	0.047	0.052
21	0.042	0.047
22	0.039	0.044
23	0.036	0.040
24	0.022	0.028
Sum	1.000	1.000

E3.2 Distribution System Multiplier (DSM) within the Dwelling Unit

The distribution system multiplier (unitless) is an adjustment for alternative water heating distribution systems within the dwelling unit. A value of one is used for standard distribution systems defined as a "main and branch" piping system with the portion of all lines leading from the water heater to the kitchen fixtures are insulated to a nominal R-4. For single family buildings, vValues for alternative distribution systems are given in Table RE-2. For multi-family buildings, DSM is 1.2, which is equivalent to "Standard pipes with no insulation" in Table RE-2.

Table RE-2 Distribution System Multipliers within a Dwelling Unit with One or More Water Heaters

Distribution System Measure	Code	DSM
Pipe Insulation (all lines)	PIA	0.90
Uninsulated Pipe below Grade	UPBG	3.80
Insulated and Protected pipe below grade	IPBG	1.0
Point of Use	POU	0.00
Standard -Kitchen Pipe Insulation– Standard Case	STD	1.00
Standard pipes with no insulation	SNI	1.20
Parallel Piping	PP	1.00
Recirculation (no control)	RNC	4.50
Recirculation + timer control	RTm	3.00
Recirculation + temperature control	RTmp	3.70
Recirculation + timer/temperature	RTmTmp	2.50
Recirculation + demand manual control	RDmm	0.90
Recirculation + demand motion-sensor control	RDms	1.0
Temperature Buffering Tank	TBT	1.2

For eligibility criteria for distribution systems see Reference Residential Appendix RA4.4.

E3.3 Cold Water Inlet Temperature

The water inlet temperature varies monthly by climate zone and is equal to the assumed ground temperature as shown in Table RE-3.

Table RE-3 Monthly Ground Temperature (ºF)

Climate Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4
2	53.3	51.5	51.4	52.2	55.6	58.9	61.8	63.6	63.8	62.3	59.5	56.3
3	55.1	54.1	54.0	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9
4	55.5	54.0	53.9	54.6	57.5	60.3	62.8	64.3	64.5	63.2	60.8	58.0
5	55.7	54.8	54.7	55.2	56.9	58.7	60.2	61.1	61.2	60.4	59.0	57.3
6	59.1	58.1	58.0	58.5	60.4	62.4	64.0	65.1	65.2	64.3	62.7	60.8
7	60.1	59.1	59.0	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9
8	60.0	58.8	58.7	59.2	61.6	63.9	66.0	67.3	67.4	66.3	64.3	62.1
9	60.5	59.1	59.0	59.7	62.2	64.8	67.1	68.5	68.6	67.5	65.3	62.8
10	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4
11	54.9	52.4	52.2	53.4	58.2	63.0	67.2	69.8	70.0	67.9	63.8	59.2
12	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67.0	67.2	65.4	62.0	58.1
13	57.5	54.7	54.5	55.8	61.0	66.2	70.6	73.5	73.7	71.4	67.0	62.0
14	54.2	51.2	51.0	52.4	58.2	63.9	68.8	72.0	72.2	69.7	64.8	59.3
15	66.8	64.0	63.8	65.1	70.4	75.8	80.4	83.3	83.6	81.2	76.7	71.5
16	44.4	41.8	41.6	42.8	47.7	52.6	56.8	59.5	59.7	57.5	53.4	48.7

E4 Hourly Recirculation Distribution Loss for Central Water Heating Systems

This section is applicable to the DHW system type 4, as defined in E1 Purpose and Scope. The distribution losses accounted for in the distribution ~~system~~ loss multiplier (D~~S~~LM), Equation RE-4, ~~see table RE-2~~ ~~are~~reflect distribution heat loss within each individual dwelling unit. Additional distribution losses occur~~ in most multi-family~~ outside dwelling units ~~related to recirculation systems~~ and ~~between dwelling units. These losses~~

they include losses from piping that is or could be part of a recirculation loop pipes and branch pipesing to individual residential dwelling units. The hourly values of these losses, HRDL, shall be calculated according to Equation RE-10. Compliance software shall provide input for specifying recirculation system designs and controls according to the following algorithms.. These losses are divided into losses to the outside air, the ground and the conditioned or semi-conditioned air within the building envelope.

Equation RE-10 $HRDL_k = NLoop_k \times HRLL_k + HRBL_k$

where

$HRDL_k$= Hourly recirculation loop and branch pipe distribution loss for k^{th} system (Btu).

$HRLL_k$= Hourly recirculation loop pipe heat loss (Btu). See equation RE-11

$HRBL_k$= Hourly recirculation branch pipe heat loss (Btu). See equation RE-19

$NLoop_k$= Number of recirculation loop in water heating system k. See section E4.3

A recirculation loop usually include multiple pipe sections with different pipe diameters, which are exposed to different ambient conditions. The compliance software shall provide input entries for up to six pipe sections with three sections for supply piping and three sections for return piping for users to describe the configurations of the recirculation loop. For each of the six pipe sections, input entries shall include pipe diameter (inch), pipe length (ft), and ambient conditions. Ambient condition input shall include three options: outside air, underground, conditioned or semi-conditioned air.

Outside air includes crawl spaces, unconditioned garages, unconditioned equipment rooms, as well as actual outside air. Solar radiation gains are not included in the calculation because the impact of radiation gains is relatively minimal compared to other effects. Additionally, the differences in solar gains for the various conditions (e.g., extra insulation vs. minimum insulation) are relatively even less significant.

The ground condition includes any portion of the distribution piping that is underground, including that in or under a slab. Insulation in contact with the ground must meet all the requirements of Section 150 (j), Part 6, of Title 24.

The losses to conditioned or semi-conditioned air include losses from any distribution system piping that is in an attic space, within walls (interior, exterior or between conditioned and unconditioned spaces), within chases on the interior of the building, or within horizontal spaces between or above conditioned spaces. It does not include the pipes within the residence. The distribution piping stops at the point where it first meets the boundaries of the dwelling unit.

Hourly recirculation loop pipe heat loss ($HRLL_k$) is the hourly heat loss from all six pipe sections. There are two pipe heat loss modes, pipe heat loss with non-zero water flow (PLWF) and pipe heat loss without hot water flow (PLCD). The latter happens when the recirculation pump is turned off by a control system and there is no hot water draw flows, such as in recirculation return pipes. Pipe heat loss modes are determined by recirculation control schedules and hot water draw schedules. For each pipe section, hourly pipe heat loss is the sum of heat loss from the two heat loss modes. Hourly heat loss for the whole recirculation loop ($HRLL_k$) is the heat loss from all six pipe sections, according to the following equation:

Equation RE-11 $HRLL_k = \sum_n (PLWF_n + PLCD_n)$

where

$PLWF_n$= Hourly pipe heat loss with non-zero water flow (Btu/hr). See equation RE-12

$PLCD_n$= Hourly pipe heat loss without water flow (Btu/hr). See equation RE-16

n= Recirculation pipe section index, 1-6.

Equation RE-12 $PLWF_n = Flow_n \cdot \rho \cdot C_p \cdot (T_{IN,n} - T_{OUT,n})$

where

$Flow_n$ = Hourly water flow in section n (gallons). See equation RE-13

ρ = Density of water, 8.3 (lb/gallon).

C_p = Heat Capacity of water, 1 (Btu/lb/^{o}F).

$T_{IN,n}$ = Input temperature of section n (^{o}F). For the first section (n=1), $T_{IN,1}$ shall be determined based on Table RE-4. The control schedule of the proposed design shall be based on user input. The standard design is demand control. For other sections, input temperature is the same as the output temperature the proceeding pipe section, $T_{IN,n} = T_{OUT,n-1}$. A proposed design may not provide input for all pipe sections, the compliance software shall treat all sections with input as connected in sequence.

$T_{OUT,n}$ = Output temperature of section n (^{o}F). See equation RE-14

Equation RE-13 $Flow_n = Flow_{Draw,n} + Flow_{Recirc} \cdot SCH_{k,m}$

where

$Flow_{Draw,n}$ = Hourly hot water draw flow (gallon). For supply sections, n=1, 2, or 3, $Flow_{Draw,n} = GPH_k/NLoop$. For return pipes, n=4, 5,and 6, $Flow_{Draw,n} = 0$.

$Flow_{Recirc}$ = Hourly recirculation flow (gallon). It is assumed to be 360 gallons based on the assumption that the recirculation flow rate is 6 GPM.

$SCH_{k,m}$ = Recirculation pump operation schedule, representing the fraction of the hour that the recirculation pump is turned off, see Table RE-4. Operation schedule for the proposed design shall be based on user input. The standard design is demand control.

Equation RE-14 $$T_{OUT,n} = T_{Amb,n} + \left(T_{IN,n} - T_{Amb,n}\right) \cdot e^{-\frac{UA_n}{\rho \cdot c_p \cdot Flow_n}}$$

where

$T_{Amb,n}$ = Ambient temperature of section n (^{o}F), which can be outside air, underground, conditioned or semi-conditioned air. Outside air temperatures shall be the dry-bulb temperature from the weather file. Underground temperatures shall be obtained from Table RE-3. Hourly conditioned air temperatures shall be the same as conditioned space temperature. For the proposed design, $T_{Amb,n}$ options shall be based on user input. The standard design assumes all pipes are in conditioned air.

UA_n = Heat loss rate of section n (Btu/hr-°F). See equation RE-15 and RE-16

Equation RE-15 is for standard design with extra 0.5 inch of insulation and Equation RE-16 is for minimum pipe insulation.

Equation RE-15 $$UA_n = \left(\pi \cdot \frac{Dia_n}{12} \cdot Len_n\right) \cdot \left(\frac{cond}{\frac{Dia_n}{2 \cdot 12} \cdot ln\left(\frac{Dia_n + 2 \cdot (Thick + 0.5)}{Dia_n}\right)}\right) \cdot f_{UA} \cdot f_{Area}$$

Equation RE-16 $$UA_n = \left(\pi \cdot \frac{Dia_n}{12} \cdot Len_n\right) \cdot \left(\frac{cond}{\frac{Dia_n}{2 \cdot 12} \cdot ln\left(\frac{Dia_n + 2 \cdot Thick}{Dia_n}\right)}\right) \cdot f_{UA} \cdot f_{Area}$$

where

π = 3.14159265

Dia_n = Section n pipe diameter (inch). It is divided by 12 in the above equation to convert the unit from inch to foot. For the proposed design, use user input; for the standard design, see Equation RE-28.

Len_n = Section n pipe length (foot). For the proposed design, use user input; for the standard design, see Equation RE-27.

Thick = Pipe insulation minimum thickness (inch) as defined in the Title 24 Section 123, TABLE 123-A for service hot water system.

cond = Insulation conductivity shall be assumed 0.26 (Btu inch/h·sf·F)

f_{UA} = Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculation. It is assumed to be 2.0.

f_{area} = The multiplier to adjust proposed design based on pipe surface area validation. See Equation RE-29

Pipe heat loss without water flow shall be calculated according to the following equations:

Equation RE-17 $PLCD_n = Vol_n \cdot \rho \cdot C_p \cdot (T_{Start,n} - T_{End,n})$

Equation RE-18 $T_{End,n} = T_{Amb,n} + \left(T_{Start,n} - T_{Amb,n}\right) \cdot e^{-\frac{UA_n}{Vol_n \cdot \rho \cdot C_p \cdot f_{UA}} \cdot (1 - SCH_{k,m})}$

where

Vol_n = Volume of section n (gallons). It is calculated as $7.48 \cdot \pi \cdot \left(\frac{Dia_s + 0.125}{24}\right)^2 \cdot Len_n$, where 0.125 inch is added to reflect thermal mass of the pipe and 7.48 is the unit conversion factor for cubit foot to gallons.

$T_{Start,n}$ = Section n temperature at the beginning of recirculation pump being turned off (^oF). It is the average of $T_{IN,n}$ and $T_{Out,n}$, or $(T_{IN,n} + T_{Out,n})/2$.

$T_{End,n}$ = Section n temperature at the end of recirculation pump being turned off (^oF). See Equation RE-18.

Compliance software shall be able to model four recirculation control scenarios using control schedules listed in Table RE-4. A proposed design shall select a control type from one of the four options. Standard design shall use demand control.

Table RE-4 Recirculation Loop Supply Temperature and Pump Operation Schedule

Hour	No Control		Demand Control		Temperature Modulation		Temperature Modulation with Continuous Monitoring	
	$T_{IN,1}$ (°F)	$SCH_{k,m}$	$T_{IN,1}$ (°F)	$SCH_{k,m}$	$T_{IN,1}$ (°F)	$SCH_{k,m}$	$T_{IN,1}$ (°F)	$SCH_{k,m}$
1	135	1	135	0.2	125	1	120	1
2	135	1	135	0.2	125	1	120	1
3	135	1	135	0.2	125	1	120	1
4	135	1	135	0.2	125	1	120	1
5	135	1	135	0.2	125	1	120	1
6	135	1	135	0.2	130	1	125	1
7	135	1	135	0.2	135	1	130	1
8	135	1	135	0.2	135	1	130	1
9	135	1	135	0.2	135	1	130	1
10	135	1	135	0.2	135	1	130	1
11	135	1	135	0.2	135	1	130	1
12	135	1	135	0.2	135	1	130	1
13	135	1	135	0.2	135	1	130	1
14	135	1	135	0.2	135	1	130	1
15	135	1	135	0.2	135	1	130	1
16	135	1	135	0.2	135	1	130	1
17	135	1	135	0.2	135	1	130	1
18	135	1	135	0.2	135	1	130	1
19	135	1	135	0.2	135	1	130	1
20	135	1	135	0.2	135	1	130	1
21	135	1	135	0.2	135	1	130	1
22	135	1	135	0.2	135	1	130	1
23	135	1	135	0.2	135	1	130	1
24	135	1	135	0.2	130	1	125	1

E4.2 Hourly Recirculation Branch Pipe Heat Loss Calculation

The proposed design and standard design shall use the same branch pipe heat loss assumptions. Branch pipe heat loss is made up of two components. First, pipe heat losses occur when hot water is in use (HBUL).

Second, there could be losses associated with hot water waste (HBWL) when hot water was used to displace cold water in branch pipes and hot water is left in pipe to cool down after hot water draws. and must be dumped down the drain. The Total Hourly Branch Losses ($HRBL_k$) shall include both components and be calculated as:

Equation RE-19 $HRBL_k = Nbranch_k \times (HBUL + HBWL)$

where

HBUL = Hourly pipe loss for one branch when water is in use (Btu/hr). See Equation RE-20

HBWL = Hourly pipe loss for one branch due to hot water waste (Btu/hr). See Equation RE-23

$Nbranch_k$ = Number of branches in water heating system k. See Equation RE-31

The hourly branch pipe loss while water is calculated in the same way as recirculation pipe heat loss with non-zero water flow (PLWF) using the following equations:

Equation RE-20 $HBUL = \left(\frac{GPH_k}{Nbranch_k}\right) \cdot \rho \cdot C_p \cdot (T_{IN,b} - T_{OUT,b})$

where

$T_{IN,b}$ = Average branch input temperature (^{o}F). It is assumed to be equal to the output temperature of the first recirculation loop section, $T_{OUT,1}$.

$T_{OUT,b}$ = Average branch output temperature (^{o}F). See equation RE-21

Equation RE-21 $T_{OUT,b} = T_{Amb,b} + (T_{IN,b} - T_{Amb,b}) \times e^{-\frac{UA_b}{\rho \cdot C_p \cdot Flow_b}}$

where

$T_{Amb,b}$ = Branch pipe ambient temperature (°F) Branch pipes are assumed to be located in the conditioned or semi-conditioned air.

UA_b = Branch pipe heat loss rate (Btu/hr-°F). See equation RE-22

$Flow_b$ = Average branch hot water flow rate (Gal/hr). It is assumed to be 2 GPM or 120 Gal/hr.

Equation RE-22 $UA_b = \left(\pi \cdot \frac{Dia_b}{12} \cdot Len_b\right) \cdot \left(\frac{cond}{\frac{Dia_b}{2 \cdot 12} \cdot ln\left(\frac{Dia_b + 2 \cdot Thick_b}{Dia_b}\right)}\right)$

where

π = 3.14159265

Dia_b = Branch pipe diameter (inch). It is divided by 12 in the above equation to convert the unit from inch to foot. See Equation RE-32

Len_b = Branch pipe length (foot). See Equation RE-33

$Thick_b$ = Branch pipe insulation thickness (inch). Since not all branch piping is required to be insulated, it shall be assumed to be 0.5 inch.

cond = Insulation conductivity, (assumed 0.26 Btu inch/h·sf·F)

where

Equation 23 $$HBWL = \left(N_{waste} \cdot SCH_{waste,m}\right) \cdot \left(f_{vol} \cdot 7.84 \cdot \pi \cdot \left(\frac{Dia_b}{24}\right)^2 \cdot Len_b\right) \cdot \rho \cdot C_p \cdot \left(T_{IN,b} - T_{Inlet}\right)$$

where

N_{waste} = Number of times in a day for which water is dumped before use. It depends on the number of dwelling units served by a branch. Statistically, the less times of water waste is inversely proportional to the number of units a branch serves. See Equation RE-24

$SCH_{waste,m}$ = Hourly schedule of water waste. See Table RE-5 Branch Water Waste Schedule.

f_{vol} = The volume of hot water waste is more than just the volume of branch pipes, due to branch pipe heating, imperfect mixing, and user behaviors. This multiplier is applied to include these effects and is assumed to be 1.4.

$T_{IN,b}$ = Average branch input temperature (°F). It is assumed to equal to the output temperature of the first recirculation loop section, $T_{OUT,1}$.

T_{inlet} = The cold water inlet temperature (ºF) according to Table RE3.3 Cold Water Inlet Temperature.

Equation 24 $$N_{waste} = 19.84 \cdot e^{\left(-0.544 \cdot N_{unit,b}\right)}$$

where

$N_{unit,b}$= Number of dwelling units served by the branch. See Equation RE-30

Hourly water waste in gallons (HBWW) for water heating system k can be calculated as:

Equation 25 $$HBWW_k = Nbranch_k \cdot \left(f_{vol} \cdot \pi \cdot \left(\frac{Dia_b}{24}\right)^2 \cdot Len_b\right)$$

Table RE-5 Branch Water Waste Schedule

Hour	$SCH_{waste,m}$
1	0.01
2	0.02
3	0.05
4	0.22
5	0.25
6	0.22
7	0.06
8	0.01
9	0.01
10	0.01
11	0.01
12	0.01
13	0.01
14	0.01
15	0.01
16	0.01
17	0.01
18	0.01
19	0.01
20	0.01
21	0.01
22	0.01
23	0.01
24	0.01

E4.3 Recirculation System Plumbing Designs

The compliance software shall provide default and standard recirculation system designs according to the following procedures. The default design reflects typical recirculation loop design practices and is used to validate the proposed design. The standards design represents an improved design with two recirculation loops and is used to set recirculation loop heat loss budget.

The first step is to determine the number of recirculation loops, Nloop, in water heating system k. The default design has one recirculation loop, Nloop =1, while the standard design has two recirculation loop, Nloop =2. Proposed designs are allowed to specify multiple loops only if the recirculation loop designs are verified by a HERS rater. Otherwise, they shall use the default value of 1.

The standard and default recirculation loop designs are based on characteristics of the proposed building. Proposed buildings are assumed to have same dwelling units on each floor and each floor has a corridor with dwelling units on both sides. The main recirculation loop sections are located in the middle-floor corridor ceiling. Both supply sections and return sections cover the length of the corridor, which is about the length of each dwelling unit multiplied by half of the number of dwelling unit on one floor. Additional piping is added for connecting the main recirculation loop to the mechanical room, which houses the water heaters or boilers and the recirculation pump. Each recirculation loop design includes six pipe sections, three supply sections and three return sections. Pipe sizes are determined based on the number of dwelling units served by the loop, following the 2009 Uniform Plumbing Code (UPC) pipe sizing guidelines.

Both the standard and default recirculation loop designs are assumed to have equal length of supply sections and return sections. The first section is from the mechanical room to the first branch. The second section serves first half branches connected to the loop and the third section serves the rest branches. The first and second sections have the same pipe diameter. Pipe size for the third section is reduced since less dwelling units are served. Return sections are in the same locations but in the opposite direction. As a result, return section lengths match the corresponding supply sections. All return sections have the same diameter. In the standard design, mechanical room is optimally located so that only vertical piping between the mechanical room and the main recirculation loop is needed. In the default design, the recirculation loop travels 1/3 of the building length horizontally before go vertically to the main loop. The detailed recirculation loop configurations are calculated as following:

Pipe Length in the mechanical room (feet): $L_{mech} = 8$

Height of each floor (feet): $H_{floor} = 10$

Length of each dwelling unit (feet): $L_{unit} = \sqrt{CFA_i}$

Section length (feet):

Equation RE-26 Default Design

$$Len_1 = L_{mech} + L_{unit} \cdot \frac{Nunit}{2 \cdot Nk \cdot Nfloor} \cdot \frac{1}{3} + H_{floor} \cdot \frac{Nfloor}{2}$$

$$Len_2 = L_{unit} \cdot \frac{Nunit}{4 \cdot Nk \cdot Nfloor}$$

$$Len_3 = Len_2$$

$$Len_4 = Len_3$$

$$Len_5 = Len_2$$

$$Len_6 = Len_1$$

Equation RE-27 Standard Design

$$Len_1 = L_{mech} + H_{floor} \cdot \frac{Nfloor}{2}$$

$$Len_2 = L_{unit} \cdot \frac{Nunit}{8 \cdot Nk \cdot Nfloor}$$

$$Len_3 = Len_2$$

$$Len_4 = Len_3$$

$$Len_5 = Len_2$$

$$Len_6 = Len_1$$

Pipe diameters (inch) for supply sections depends on the number of dwelling units being served. They shall be calculated using the look up table of RE-6 according to the number of dwelling unit served by the corresponding supply section, or using the formula below. Both methods are based on 2009 UPC pipe sizing specifications.

Equation RE-28

$$Dia_1 = INT((-7.525 \cdot 10^{-9} \cdot N_{unit,1}\text{^}4 + 2.82 \cdot 10^{-6} \cdot N_{unit,1}\text{^}3 - 4.207 \cdot 10^{-4} \cdot N_{unit,1}\text{^}2 + 0.04378 \cdot N_{unit,1} + 1.232)/0.5 + 1) \cdot 0.5$$

$$Dia_2 = Dia_1$$

$$Dia_3 = INT((-7.525 \cdot 10^{-9} \cdot N_{unit,3}\text{^}4 + 2.82 \cdot 10^{-6} \cdot N_{unit,3}\text{^}3 - 4.207 \cdot 10^{-4} \cdot N_{unit,3}\text{^}2 + 0.04378 \cdot N_{unit,3} + 1.232)/0.5 + 1) \cdot 0.5$$

$Dia_4 = Dia_5 = Dia_6 = 0.75$ for low-rise multi-family building and hotel/motel less than four stories

$Dia_4 = Dia_5 = Dia_6 = 1$ for high-rise multi-family and hotel/motel more than three stories

where

Nunit = Number of dwelling unit in the building.

Nfloor = Number of floors of the building.

Nk = Number of water heating system in the building.

$N_{unit,1}$= Number of dwelling unit served by the section 1. $N_{unit,1} = \frac{Nunit}{Nk \cdot Nfloor \cdot Nloop}$

$N_{unit,3}$= number of dwelling unit served by the section 3, $N_{unit,3} = \frac{N_{unit,1}}{2}$.

Total recirculation loop pipe surface area for the default design is calculated and used to validated the proposed design inputs according to the following equation:

Equation RE-29

$$f_{area} = 1 \left(for \ \frac{SF_{Default}}{SF_{Proposed}} < 1.0\right) \ or \ \frac{SF_{Default}}{SF_{Proposed}} \left(for \ \frac{SF_{Default}}{SF_{Proposed}} \geq 1.0\right)$$

where

$SF_{Proposed}$ = Proposed design recirculation loop surface area (sqft), $\sum_s \pi \cdot Dia_s \cdot Len_s$ based on proposed design inputs

$SF_{Default}$ = Default design recirculation loop surface area (sqft), $\sum_s \pi \cdot Dia_s \cdot Len_s$ based on default design parameters

Branch design parameters include number of branches, branch length, and branch diameter. The standard design assumes that the dwelling units are evenly distributed on each floor and one branch is needed for each dwelling unit on a floor. Therefore, the number of branches in water heating system k is calculated as:

Equation RE-30 $N_{unit,b} = Nfloor$

Equation RE-31 $Nbranch_k = INT(\frac{Nunit}{N_{unit,b} \cdot NK} + 0.5)$

where

$N_{unit,b}$= Number of dwelling unit served by each branch

$Nbranch_k$= Number of branch in water heating system k

The branch pipe diameter shall be calculated using the look up table of RE-6 according to the number of dwelling unit served by the branch, or using the formula below. Both methods are based on 2009 UPC pipe sizing specifications..

Equation RE-32

$$Dia_b = INT((-7.525 \cdot 10^{-9} \cdot N_{unit,b}\hat{}4 + 2.82 \cdot 10^{-6} \cdot N_{unit,b}\hat{}3 - 4.207 \cdot 10^{-4} \cdot N_{unit,b}\hat{}2 + 0.04378 \cdot N_{unit,b} + 1.232)/0.5 + 1) \cdot 0.5$$

The branch length includes the vertical rise based on the number of floors in the building plus four feet of pipe to connect the branch to the recirculation loop.

Equation RE-33 $Len_b = 4 + H_{floor} \cdot (Nfloor - 1)$

Propose designs shall use the branch configurations as those in the standard design. Therefore, compliance software do not need to collect branch design information.

Table RE-6 Pipe Sizing Schedule

Number of Dwelling Units	**Pipe Diameter (inch)**
<8	**1.5**
8 – 20	**2**
21 – 42	**2.5**
43 – 67	**3**
68 – 100	**3.5**
101 – 144	**4**

These losses are added to the load accounted for in the hourly adjusted recovery load HARL, according to Equation RE-1 and calculated in the following equation.

Equation RE-11 $$HRDL_k = NL_{OA} \times UA_{OA} \times (T_s - T_{OA}) + NL_{UG} \times UA_{UG} \times (T_s - T_G) + NL_P \times UA_P$$

where

$HRDL_k$ = Hourly recirculation distribution loss (Million Btu).

T_s = Hot water supply temperature of 135°F.

T_{OA} = Hourly dry-bulb temperature of outside air (°F).

T_G = Hourly ground temperature (°F) assumed constant for each month See Table RE-3.

NL_{OA} = Normalized load coefficient for outside air term. See equation RE-12

NL_{UG} = Normalized load coefficient for underground term. See equation RE-13

NL_P = Normalized load coefficient for conditioned or semi-conditioned term. See equation RE-14

UA_{OA} = Heat loss rate of circulation pipe exposed to outside air (Btu/hr-°F). See equation RE-19UA_{UG} = Heat loss rate of circulation pipe buried under ground (Btu/hr-°F)). See equation RE-20

UA_P = Heat loss rate of circulation pipe in conditioned or semi-conditioned space (Btu/hr-°F).). See Equation RE-19 or 20

MSC = 0.80 Multiplier - Adjustment factor for installation of monitoring equipment or demand modulated equipment . See eligibility criteria in Reference Residential Appendix RA4.4.9.2 for installation requirements

The terms UA_{OA}, UA_{UG}, and UA_P represent the conductive area and heat loss rate for the three pipe locations. In each case the UA is a function of the pipe length, pipe diameter and pipe insulation. The program user will need to specify pipe length in each of the three locations, and specify the insulation as being either minimum (as specified in Section 150 (j), Part 6, of Title 24), or extra. Length and corresponding insulation R-value takeoffs are required for piping in each of the three locations (outdoors, underground, and conditioned or semi-conditioned space). Pipe heat loss rates (UA_{OA}, UA_{UG}, and UA_p) are then calculated for use in Equation RE-11.

The normalized load coefficients, NL_{OA}, NL_{UG}, and NL_P, are climate zone specific multipliers for the pipe losses to the outside air, underground and conditioned or semi-conditioned space, respectively. They are calculated according to the following equations:

Equation RE-12 $$NL_{OA} = \frac{C_{OA1} \times \exp\left(\frac{C_{OA2} \times UA_{OA}}{GPD_k}\right)}{WHDH_{OA}}$$

Equation RE-13 $$NL_{UG} = \frac{C_{UG1} \times \exp\left(\frac{C_{UG2} \times UA_{UG}}{GPD_k}\right)}{WHDH_{UG}}$$

Equation RE-14 $$NL_P = \frac{C_{P1} \times \exp\left(\frac{C_{P2} \times UA_P}{GPD_k}\right)}{8760}$$

where

GPD_k = The hot water consumption per day for the k[th] system. It is the sum of hot water consumption per day for all dwelling units served by the k[th] system.

$WHDH_{OA}$ = Water heating degree hours based on outside air temperature (hr-°F).

$WHDH_{UG}$ = Water heating degree hours based on ground temperature (hr-°F).

C_{OA1}, C_{OA2} = Coefficients for outside air pipe loss term.

C_{UG1}, C_{UG2} = Coefficients for underground pipe loss term.

C_{P1}, C_{P2} = coefficients for conditioned or semi-conditioned space pipe loss term.

Coefficients of C_{OA}, C_{UG}, and C_P vary by climate zones and control schemes of the circulation system. Table RE-4 lists values of these coefficients.

Table RE-4 Coefficients of C_{OA}, C_{UG} and C_P

Climate Zone	No Controls						Timer Controls					
	COA1	COA2	CUG1	CUG2	CP1	CP2	COA1	COA2	CUG1	CUG2	CP1	CP2
1	0.8933	-0.694	0.8922	-1.346	0.6259	-1.673	0.8658	-2.336	0.793	-2.062	0.6344	-4.475
2	0.854	-0.71	0.8524	-1.348	0.6433	-1.383	0.8269	-2.456	0.7572	-2.056	0.6529	-4.138
3	0.8524	-0.709	0.851	-1.355	0.6826	-1.464	0.8252	-2.37	0.7553	-2.049	0.6927	-4.438
4	0.8349	-0.688	0.8345	-1.343	0.6502	-0.706	0.8096	-2.433	0.7427	-2.071	0.667	-3.759
5	0.8494	-0.706	0.8476	-1.341	0.6873	-1.076	0.8218	-2.409	0.7536	-2.061	0.6922	-3.979
6	0.8095	-0.704	0.808	-1.341	0.7356	-1.697	0.7836	-2.367	0.718	-2.059	0.7341	-4.512
7	0.796	-0.673	0.7964	-1.349	0.735	-1.581	0.7734	-2.395	0.7082	-2.064	0.7416	-4.579
8	0.7941	-0.704	0.7925	-1.341	0.7321	-1.471	0.7683	-2.414	0.7049	-2.064	0.7333	-4.318
9	0.7853	-0.707	0.7843	-1.352	0.7208	-1.212	0.7599	-2.447	0.6971	-2.064	0.7248	-4.141
10	0.7854	-0.714	0.7843	-1.352	0.7193	-1.273	0.7595	-2.5	0.6971	-2.067	0.7188	-4.041
11	0.8137	-0.69	0.8139	-1.35	0.6149	-1.22	0.788	-2.443	0.7228	-2.051	0.6315	-4.306
12	0.8283	-0.685	0.8286	-1.349	0.6001	-0.323	0.8029	-2.451	0.7367	-2.061	0.621	-3.493
13	0.7818	-0.705	0.7813	-1.352	0.6699	-1.541	0.7564	-2.465	0.6937	-2.052	0.6752	-4.305
14	0.8094	-0.706	0.809	-1.351	0.6424	-0.866	0.784	-2.49	0.7187	-2.059	0.6515	-3.588
15	0.6759	-0.692	0.6764	-1.348	0.7514	-1.383	0.6535	-2.552	0.601	-2.061	0.7493	-4.182
16	0.9297	-0.701	0.929	-1.352	0.5231	-1.519	0.9007	-2.401	0.825	-2.053	0.5437	-4.423

Table RE-4 provides coefficients for recirculation systems where the pumps are always on and coefficients for recirculation systems that are shut off during hours 1 through 5, and hours 23 and 24 (from 10p.m. to 5a.m.). Except for systems serving only a very small number of dwelling units, there is no set of coefficients provided for the case where the circulation system does not rely on a recirculation pump. Such a system would be unlikely to supply hot water within parameters acceptable to tenants. It can be assumed that any distribution systems for supplying hot water from a central boiler or water heater require a recirculation pump and one would be supplied retroactively if not initially. For central hot water systems serving six or fewer dwelling units which have (1) less than 25' of distribution piping outdoors; (2) zero distribution piping underground; (3) no recirculation pump; and (4) insulation on distribution piping that meets the requirements of Section 150 (j) of Title 24, Part 6, the distribution system in the Standard Design will assume a pump with timer controls.

$WHDH_{OA}$ is the sum of the differences between the temperature of the supply hot water (135˚F) and the hourly outdoor temperature for all 8760 hours of the year. This term varies by climate zone. The values for this term are listed in Table RE-5 below. The equation uses the hourly outdoor temperatures from the weather files incorporated in the CEC approved programs.

$WHDH_{UG}$ is the sum of the differences between the supply hot water temperature (135˚F) and the hourly ground temperature for all 8760 hours of the year. This term varies by climate zone. The appropriate values for this term are listed in Table RE-5 below. The equation uses the ground temperatures from the weather files incorporated in the CEC approved programs, which are assumed to be stable on a monthly basis.

Table RE-5 Water Heating Degree Hours for Outside Air and Underground

Climate Zone	$WHDH_{OA}$ (hr-°F)	$WHDH_{UG}$ (hr-°F)
1	712810	710306
2	680634	678425
3	679350	677026
4	666823	664459
5	677373	674935
6	645603	643236
7	636342	633811
8	633244	630782
9	626251	623822
10	625938	623741
11	649661	647770
12	661719	659676
13	623482	621526
14	645367	643517
15	539736	537782
16	741372	739378

UA terms are calculated using inputs provided by the user and base assumptions about the pipe diameter: The user inputs are:

1. Pipe length in each of the three locations.
2. Insulation R value of the pipe in each location.
3. Number of stories above grade.
4. Number of apartment units.

The total length of the circulation pipe is calculated, along with the fraction in each location (PF_{OA}, PF_{UG} and PF_P). The square feet of surface area is calculated according to the following equation:

Equation RE-15

$$SF_{total} = LF_{total} \times Dia \times \pi$$

where

SF_{Total} = The total surface area of the circulation piping, square feet.

LF_{Total} = The total lineal feet of all circulation piping, feet.Dia = Average calculated (Equation RE-) diameter of pipe in circulation piping, feet.

π = Pi (ratio of circle's circumference to its diameter), 3.1416

The average diameter of hot water piping, Dia, is calculated by the following equation:

Equation RE-16

$$Dia = 0.045 \times \left(\frac{LF_{Total}}{\Delta P}\right)^{0.21} \times (AptGPM)^{0.37} \times \frac{(NumApts)^{0.37}}{1.37}$$

The terms of the above equation are described below. The total system pressure drop, ΔP, given in psf is calculated in Equation RE-17.

Equation RE-17

$$\Delta P = \left[P_{meter} - 4.3 \times (NumStories - 1) - 15\right] \times 144$$

where

P_{meter} = Water system supply pressure, (60 psig by assumption).

~~NumStories = Number of stories above grade, (but enter "4" if more than 4 stories).~~

~~Equation RE-18~~ $$AptGPM = \frac{1.765 \times (12 \times NumApts)^{0.687}}{NumApts}$$

~~NumApts = Number of apartments in the building served by the hot water system, apts~~

~~The UA for each of the three locations is derived as a function of the fraction of the total pipe in that location times a factor that represents the conductivity of the standard (minimum) insulation or the "extra" insulation condition. The following two equations provide the alternate equations for the two insulation cases. The factors do not vary by location so the equations for the other two locations are of exactly the same form, varying only by the fraction of pipe in that location.~~

~~The benefits of additional insulation shall be calculated as required in Section 150 (j) of Title 24. The insulation value of the ground and of protective coverings may not be used for achieving the minimum insulation values required by Section 150 (j). To qualify as extra insulation, the insulation must be at least 1/2" thicker than the insulation required by Section 150 (j).~~

~~Equation RE-19 For extra insulation for the standard design:~~ $$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick + 0.5}{Radius}\right)} \right)$$

~~Equation RE-20 For minimum insulation:~~ $$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick}{Radius}\right)} \right)$$

~~where~~

~~i = Subscript indicating pipe location OA = outside, UG = underground, P = conditioned or semi-conditioned space~~

~~PF_i = Pipe fraction in i^{th} location, no units~~

~~k = Insulation conductivity, (assumed 0.25 Btu inch/h-sf-°F)~~

~~Radius = Average pipe radius in inches, (Radius = Dia x 12 / 2), inches~~

~~Thick = Base case insulation thickness, Thick = 1 if average pipe radius is less than or equal to 2";Thick = 1.5 if radius is greater than 2", inches~~

E5 High Rise Residential Buildings, Hotels and Motels

Simulations for high rise residential buildings, hotels and motels shall follow all the rules for central or individual water heating with the following exceptions.

For central systems which do not use recirculation but use electric trace heaters the program shall assume equivalency between the recirculation system and the electric trace heaters.

For individual water heater systems which use electric trace heating instead of gas the program shall assume equivalency.

E6 Energy Use of Individual Water Heaters

Once the hourly adjusted recovery load is determined for each water heater, the energy use for each water heater is calculated as described below.

E6.1 Small[1] Gas, Oil, or Electric Storage[2] and Heat Pump Water Heaters

The hourly energy use of storage gas, storage electric and heat pump water heaters is given by the following equation.

Equation RE-21

$$WHEU_j = \left[\frac{HARL_j \times HPAF_j}{LDEF_j} \right]$$

where

$WHEU_j$ = Hourly energy use of the water heater (Btu for fuel or kWh for electric), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load (Btu).

$HPAF_j$ = Heat pump adjustment factor from the table below based on climate zone. This value is one for storage gas, storage oil and storage electric water heaters.

Table RE-46 Heat Pump Adjustment Factors

Climate Zone	Heat Pump Adjustment Factor	Climate Zone	Heat Pump Adjustment Factor
1	1.040	9	0.920
2	0.990	10	0.920
3	0.990	11	0.920
4	1.070	12	1.070
5	1.070	13	0.920
6	0.920	14	1.040
7	0.920	15	0.920
8	0.920	16	1.500

$LDEF_j$ = The hourly load dependent energy factor (LDEF) is given by the following equation. This equation adjusts the standard EF for different load conditions.

Equation RE22

$$LDEF_j = e \times \left(\ln\left(\frac{HARL_j \times 24}{1000} \right)(a \times EF_j + b) + (c \times EF_j + d) \right)$$

where

a,b,c,d,e = Coefficients from the table below based on the water heater type.

---

1 "Small water heater" means a water heater that is a gas storage water heater with an input of 75,000 Btu per hour or less, an oil storage water heater with an input of 105,000 Btu per hour or less, an electric storage water heater with an input of 12 kW or less, or a heat pump water heater rated at 24 amps or less.

2 "Small storage water heater" means a water heater that is a gas storage water heater with an input of 75,000 Btu per hour or less, an oil storage water heater with an input of 105,000 Btu per hour or less, or an electric storage water heater with an input of 12 kW. A small water heater includes a heat pump water heater rated at 24 amps or less.

Table RE-~~5~~7 LDEF Coefficients

Coefficient	Storage Gas	Storage Electric	Heat Pump
a	-0.098311	-0.91263	0.44189
b	0.240182	0.94278	-0.28361
c	1.356491	4.31687	-0.71673
d	-0.872446	-3.42732	1.13480
e	0.946	0.976	0.947

Note 1: EF for storage gas water heaters under 20 gallons must be assumed to be 0.58 unless the manufacturer has voluntarily reported an actual EF to the California Energy Commission. As of April 2003, manufacturers of this equipment are no longer required to do so.

Note 2: LDEF shall not reduce the energy consumption of the proposed water heating system.

EFj = Energy factor of the water heater (unitless). This is based on the DOE test procedure.

E6.2 Small Gas or Oil Instantaneous[3]

The hourly energy use for instantaneous gas or oil water heaters is given by the following equations.

Equation RE-23

$$WHEU_j = \left(\frac{HARL_j}{EF_j * 0.92} \right)$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu).

$HARL_j$ = Hourly adjusted recovery load.

EF_j = Energy factor from the DOE test procedure (unitless). This is taken from manufacturers' literature or from the CEC Appliance Database.

0.92 = Efficiency adjustment factor

Note: Small gas or oil instantaneous water heaters can be used in conjunction with demand recirculation. No other recirculation systems may be used.

E6.3 Small Electric Instantaneous

The hourly energy use for instantaneous electric water heaters is given by the following equation.

Equation RE-24

$$WHEU_{j,electric} = \frac{HARL_j}{EF_j * 0.92}$$

where

$WHEU_{j,\ elec}$ = Hourly electricity energy use of the water heater (kWh).

$HARL_j$ = Hourly adjusted recovery load.

[3] "Instantaneous water heater" means a water heater that has an input rating of at least 4,000 Btu per hour per gallon of stored water. Small instantaneous water heaters include: gas instantaneous water heaters with an input of 200,000 Btu per hour or less, oil instantaneous water heaters with an input of 210,000 Btu 1602 per hour or less, and electric instantaneous water heaters with an input of 12 kW or less.

EF_j = Energy factor from DOE test procedure (unitless). EF is adjusted for electricity by multiplying 1000* TDV mulitiplier.

0.92 = Adjustment factor to adjust for overall performance.

E6.4 Large[4] Gas or Oil Storage

Energy use for large storage gas is determined by the following equations. Note: large storage gas water heaters are defined as any gas storage water heater with a minimum input rate of 75,000 Btu/h.

Equation RE-25

$$WHEU_j = \left[\frac{HARL_j}{EFF_j} + SBL \right]$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section RE-E3.

SBL = Total Standby Loss. Obtain from CEC Appliance Database or from manufacturer literature. This value includes tank losses and pilot energy. If standby is not reported as a value, but as a percent, then standby value shall be calculated by multiplying the input by the percent listed in the CEC Appliance Database.

EFF_j = Efficiency (fraction, not %). Obtained from CEC Appliance Database or from manufacturer's literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

E6.5 Large Instantaneous, Indirect Gas and Hot Water Supply Boilers[5]

Energy use for these types of water heaters is given by the following equation.

Equation RE-26

$$WHEU_j = \left[\frac{HARL_j}{EFF_j \times 0.92} + PILOT_j \right]$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section E3.

HJL_j = Hourly jacket loss (Btu/h) for tank rated with the water heater. To account for independent hot water storage tanks substitute $HARL_j$ (from Section E6.7 Jacket Loss~~E6.7 Jacket Loss~~) for $HARL_j$ storage tanks

4 "Large water heater" means a water heater that is not a small water heater.

5 "Hot water supply boiler" means an appliance for supplying hot water for purposes other than space heating or pool heating.

EFF_j = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

EAF_j = Efficiency adjustment factor (unitless).

$PILOT_j$ = Pilot light energy (Btu/h) for large instantaneous. For large instantaneous water heaters, and hot water supply boilers with efficiency less than 89 percent assume the default is 750 Btu/hr if no information is provided in manufacturer's literature or CEC Appliance Database.

0.92 = Adjustment factor used when system is not supplying a storage system.

E6.6 Large Electric Storage

Energy use for large storage electric water heaters is given by the following equation.

Equation RE-27

$$WHEU_{j,elec} = \left[\frac{HARL_j}{EFF\bar{j}}\right] + SBL$$

where

$WHEU_{j,\,elec}$ = Hourly electricity energy use of the water heater (kWh).

EFF_j = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

$HARL_j$ = Hourly adjusted recovery load.

SBL = Total Standby Loss. Obtain from CEC Appliance Database or from manufacturer literature. If standby is reported as a percent then the standby shall be determined by taking a percent of the equipment input rating times 3413. If no standby value is reported the standby shall be assumed to be 1 percent of the equipment input rating * 3413..

E6.7 Jacket Loss

The hourly jacket loss for the l^{th} unfired tank or indirectly fired storage tank in the k^{th} system is calculated as

Equation RE-28

$$HJL_l = \frac{TSA_l \times \Delta TS}{RTI_l + REI_l} + FTL_l$$

Where

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system

TSA_l = Tank surface area (ft^2).

ΔTS = Temperature difference between ambient surrounding water heater and hot water supply temperature (ºF). Hot water supply temperature shall be 135ºF. For water heaters located inside conditioned space use 75ºF for the ambient temperature. For water heaters located in outside conditions use hourly dry bulb temperature ambient.

FTL_l = Fitting losses. This is a constant 61.4 Btu/h.

REI_l = R-value of exterior insulating wrap. No less than R-12 is required.

RTI_I = R-value of insulation internal to water heater. Assume 0 without documentation.

E6.8 Tank Surface Area

Tank surface area (TSA) is used to calculate the hourly jacket loss (HJL) for large storage gas, indirect gas water heaters, and large storage electric water heaters. TSA is given in the following equation as a function of the tank volume.

Equation RE-29

$$TSA_j = e \times \left(f \times VOL_j^{0.33} + g\right)^2$$

where

VOL_j = Tank capacity (gallons).

e, f, g = Coefficients given in the following table.

Table RE-~~6~~8 Coefficients for Calculating Tank Surface Areas

Coefficient	Storage Gas	Large Storage Gas and Indirect Gas	Storage Electric and Heat Pumps
E	0.00793	0.01130	0.01010
F	15.67	11.8	11.8
G	1.9	5.0	5.0

E6.9 Electricity Use for Circulation Pumping

For single-family recirculation systems, hourly pumping energy is fixed as shown in following table.

Table RE-7~~9~~ Single Family Recirculation Energy Use (kWh) by Hour of Day

Hour	Uncontrolled Recirculation	Timer Control	Temperature Control	Timer/Temp Control	Demand Recirculation
1	0.040	0	0.0061	0	0.0010
2	0.040	0	0.0061	0	0.0005
3	0.040	0	0.0061	0	0.0006
4	0.040	0	0.0061	0	0.0006
5	0.040	0	0.0061	0	0.0012
6	0.040	0	0.0061	0	0.0024
7	0.040	0.040	0.0061	0.0061	0.0045
8	0.040	0.040	0.0061	0.0061	0.0057
9	0.040	0.040	0.0061	0.0061	0.0054
10	0.040	0.040	0.0061	0.0061	0.0045
11	0.040	0.040	0.0061	0.0061	0.0037
12	0.040	0.040	0.0061	0.0061	0.0028
13	0.040	0.040	0.0061	0.0061	0.0025
14	0.040	0.040	0.0061	0.0061	0.0023
15	0.040	0.040	0.0061	0.0061	0.0021
16	0.040	0.040	0.0061	0.0061	0.0019
17	0.040	0.040	0.0061	0.0061	0.0028
18	0.040	0.040	0.0061	0.0061	0.0032
19	0.040	0.040	0.0061	0.0061	0.0033
20	0.040	0.040	0.0061	0.0061	0.0031
21	0.040	0.040	0.0061	0.0061	0.0027
22	0.040	0.040	0.0061	0.0061	0.0025
23	0.040	0	0.0061	0	0.0023
24	0.040	0	0.0061	0	0.0015
Annual Total	350	234	53	35	23

Multi-family recirculation systems may have vastly different pump sizes and is therefore calculated based on the installed pump size. The hourly electricity use for pumping (HEUP) water in the circulation loop can be calculated by the hourly pumping schedule and the power of the pump motor as in the following equation.

Equation RE-30

$$HEUP_k = \frac{0.746 \times PUMP_k \times SCH_{k,m,}}{\eta_k}$$

where

$HEUP_k$ = Hourly electricity use for the circulation pump (kWh).

$PUMP_k$ = Pump brake horsepower (bhp).

η_k = Pump motor efficiency.

$SCH_{k,m}$ = Operating schedule of the circulation pump, see Table RE-4. The operating schedule for the proposed design shall be based on user input. The standard design operation schedule is demand control.~~For 24-hour operation (no controls), the value is always 1. For timer controls, the value is 1 when pump is on and 0 otherwise. The pump is assumed off from 10 p.m. to 5 a.m. and on for the remaining hours.~~

E65.10 Prorating Energy Use in Multi-Family Buildings

For central water heating systems, the energy use is calculated at the system level, not at the dwelling unit level. When it is necessary to allocate energy use to individual dwelling units for home energy ratings or other purposes, the procedure in this section may be used.

The fraction of the energy that is allocated to an individual dwelling unit is the ratio of the gallons-per-day load for that dwelling unit to the gallons-per-day estimate for the whole building. This fraction is shown in Equation RE-31.

Equation RE-31

$$Fraction_I = \frac{GPD_I}{\left(\sum_{I}^{NmbrDU} GPD_i\right)}$$

where

Fraction$_i$ = Fraction of water heating energy allocated to the ith dwelling unit.

GPD$_i$ = Gallons per day of consumption for the ith dwelling unit. See Equation RE-Equation RE-98.