CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Water and Space Heating ACM Improvement

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team — October 2011

This report was prepared by the California Statewide Utility Codes and Standards Program and funded by the California utility customers under the auspices of the California Public Utilities Commission.

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1. Introduction

This Codes and Standards Enhancement (CASE) study addresses several issues related to space heating and water heating:

- ACM algorithms for central domestic hot water (DHW) distribution system heat loss
- ACM algorithms for hydronic heating systems
- Standard design of air distribution duct in multi-family buildings
- Standard design of space heating equipment efficiency
- Pipe insulation requirement improvement

The scope of the study is mostly multi-family (low-rise and high-rise) and hotel and motel buildings. Recommended changes to standard design space heating equipment efficiency and pipe insulation will affect other nonresidential buildings.

The CASE study proposes a set of ACM algorithms for modeling central DHW recirculation system performance. The new algorithms were developed based on previous PIER studies on multi-family DHW distribution systems and continued modeling study by this CASE study. With the new ACM algorithms, energy savings from recirculation controls and recirculation loop design improvements can be calculated by compliance software. This new ACM capability would enable implementation of prescriptive requirements on DHW system controls and distribution network designs, which will be addressed by the Multi-family DHW Improvement CASE Study.

Hydronic distribution pipe heat losses are caused by the same pipe heat loss mechanisms as DHW recirculation loop heat losses. The CASE study reviewed the existing ACM algorithms for hydronic heating systems and investigated the possibility of adapting DHW pipe heat loss calculation algorithms for hydronic heating systems.

According to both the Residential and Nonresidential ACMs, air distribution loss may be included in calculating energy budget for hydronic heating systems in multi-family buildings. As a result, unnecessary compliance credits are provided to buildings using hydronic heating systems. In multi-family buildings, air distribution ducts, if they exist, are located in conditioned spaces, at least for dwelling units not on the top floor. Therefore, duct heat loss in multi-family buildings is very limited. The CASE study recommends that standard designs for multi-family building shall have the same air duct configurations as the proposed design so that no artificial duct loss credit would be provided to hydronic heating systems.

The CASE study also investigated the potential of improving the minimum efficiency requirements for wall furnaces and space heating boilers to ensure proper federal appliance efficiency standards are applied.

Lastly, using the 2013 TDV values, the CASE study assessed the cost effectiveness of increasing pipe insulation requirements for DHW and space heating systems. In addition, the study demonstrates that it is very cost effective to insulate pipes located in un-conditioned buildings and recommends that the mandatory pipe insulation requirements shall be applied to these buildings as well.

2. Overview

<table>
<tr><td>a. Measure Title</td><td>Space and Water Heating ACM Improvement</td></tr>
<tr><td>b. Description</td><td>This CASE addresses several issues related to space heating and DHW systems:
Improved central DHW ACM algorithms that can assess energy savings from recirculation loop controls and plumbing design optimization
Potential improvement of ACM algorithms for hydronic heating systems
Standard design assumptions of air distribution ducts in multi-family buildings
Minimum efficiency requirements for wall furnaces and space heating boilers
Improvement of mandatory pipe insulation requirements and expansion of mandatory pipe insulation requirements to unconditioned buildings</td></tr>
<tr><td>c. Type of Change</td><td>This CASE study recommends the following types of changes:
Modeling
Revise Residential ACM appendix E to include updated algorithms for calculating recirculation system performance with different controls and designs. The new algorithms also include a default recirculation loop design to validate proposed designs and a standard design to encourage dual-loop designs
Revise the Residential and nonresidential ACMs to specify that standard designs shall have the same air distribution duct configuration as the proposed design in multi-family (low-rise and high-rise) and motel and hotel buildings
Clarify that the space heating boilers in the System #3, #4, and #5 (Nonresidential HAVC standard designs) shall be gas hot water boilers, not steam boilers
Mandatory Measure
Increase the mandatory pipe insulation thickness for DHW system by ½ inch; require recirculation system branch pipes to be insulated to the same levels
Require pipe insulation in unconditioned buildings
Prescriptive Requirement
None</td></tr>
</table>

<table>
<tr><td>d. Energy Benefits</td><td>

The proposed DHW ACM changes will not generate direct energy savings. They are necessary for implementing prescriptive requirements on central DHW controls and recirculation loop designs, which are developed by the Multi-family DHW System Improvement CASE study. Natural gas energy savings are expected from proposed changes to standard designs and mandatory pipe insulation requirements. Details of the energy savings analysis are provided in the "*Analysis and Results*" section.

For change of air distribution duct standard design:

Per Prototype Building	Natural Gas Savings (Therms/yr)		TDV Gas Savings (kBtu/yr)	
	Low-rise	High-rise	Low-rise	High-rise
CZ1	114.4	789	12,976	132,275
CZ2	162.0	1071	18,567	189,277
CZ3	71.7	297	5,233	53,348
CZ4	103.7	572	9,535	97,196
CZ5	82.4	274	4,588	46,771
CZ6	25.8	45.0	789	8,039
CZ7	18.9	23.9	430	4,385
CZ8	32.0	86.2	1,434	14,616
CZ9	30.5	58.6	932	9,500
CZ10	54.3	193.8	3,369	34,348
CZ11	148.0	1293	21,650	220,702
CZ12	130.4	1011	16,918	172,469
CZ13	94.1	815	13,692	139,583
CZ14	144.7	1242	21,506	219,240
CZ15	14.3	75	1,219	12,424
CZ16	319.0	2356	39,070	398,286

For increasing DHW recirculation pipe insulation thickness by ½ inch:

Per foot of pipe	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (KBtu/yr)	TDV Gas Savings (KBtu/yr)
0.75"diameter	0	0	0.33	0	55
1" diameter	0	0	0.12	0	20
1.25" diameter	0	0	0.14	0	24
2" diameter	0	0	0.21	0	35
2.5" diameter	0	0	0.14	0	24
4" diameter	0	0	0.21	0	36

Statewide first year energy savings were estimated as following:

Electricity (GWh)	Demand (MW)	Natural Gas (MMtherms)	TDV Energy (TDV kBtu)
None	None	0.556	79.3×10^{6}

</td></tr>
<tr><td>e. Non-Energy Benefits</td><td>None.</td></tr>
</table>

f. Environmental Impact

The proposed changes by this CASE study will reduce natural gas consumption and, therefore, associated air pollutants emission impacts.

Emission Impacts: (Tons/year)

	NOX (Ton/yr)	SOX (Ton/yr)	CO (Ton/yr)	PM10 (Ton/yr)	CO2 (Ton/yr)
Statewide Impact	2.75	1.86	0.83	0.28	3194

The proposed improvement in DHW system recirculation loop pipe insulation will increase the use of insulation materials (fiber glass), as shown in the following table. There are no significant impacts to water use, water consumption, and water quality by this measure

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

	Mercury	Lead	Copper	Steel	Plastic	Others (fiber glass)
Per Unit Measure (per sqft of multi-family and hotel/motel buildings)	NC	NC	NC	NC	NC	0.00103
Statewide	NC	NC	NC	NC	NC	34,948

Water Consumption:

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Yr)
Per Unit Measure	NC
Per Prototype Building	NC

Water Quality Impacts:

	Mineralization (calcium, boron, & salts	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC
Comment on reasons for your impact assessment	None	None	None	None

g. Technology Measures	This CASE study does not involve the use of new technologies.
h. Performance Verification of the Proposed Measure	This CASE study does not require any new performance verification or commissioning.

i. Cost Effectiveness

Cost effectiveness of pipe insulation improvement is demonstrated using the California Energy Commission Life Cycle Costing (LCC) Methodology for the 2013 Title 24 Standards development. Representative examples are shown in the following table. More details are provided in the LCC Analysis section of the report.

a	b	c	d	e	f	g	
Measure Name DHW System Pipe Insulation	Measure Life (Years)	Additional Costs– Current Measure Costs (Relative to Basecase) ($/ft)	Additional Cost– Post-Adoption Measure Costs (Relative to Basecase) ($/ft)	PV of Additional Maintenance Costs (Savings) (Relative to Basecase) (PV$/ft)	PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per foot of Pipe ($)	
						(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
0.75" Diameter	30	$2.2	$2.2	$0	$6.4	-$4.2	-$4.2
1" Diameter	30	$2.3	$2.3	$0	$8.5	-$6.2	-$6.2
1.25" Diameter	30	$2.4	$2.4	$0	$3.1	-$0.8	-$0.8
2" Diameter	30	$2.5	$2.5	$0	$3.7	-$1.3	-$1.3
2.5" Diameter	30	$2.8	$2.8	$0	$5.5	-$2.7	-$2.7
4" Diameter	30	$3.6	$3.6	$0	$3.7	-$0.1	-$0.1

Nonresidential 30-year natural gas TDV values were used in the LCC analysis.

j. Analysis Tools	CALRES was used for low-rise multi-family energy savings analysis and EnergyPro was used for high-rise multi-family energy savings analysis. Energy savings from duct insulations were assessed based on linear pipe heat transfer analysis that included the consideration of insulation conductivity, free air convection, and pipe radiation.
k. Relationship to Other Measures	This CASE study was conducted in conjunction with the Multi-family DHW Improvement CASE study. This CASE study focused on development of ACM algorithms to assess central DHW distribution system performance and compliance verification method. The latter focused on development of prescriptive requirements on central DHW systems.

3. Methodology

This section describes the methodology used to develop ACM algorithms, energy savings, and cost effectiveness of the proposed code change.

3.1 Market Study

This CASE study was developed based on the PIER research on multi-family DHW distribution systems and further investigation of the Title 24 residential and nonresidential ACMs. The PIER research inspected DHW systems at more than 50 multi-family buildings and conducted performance monitoring studies at more than 30 multi-family building across California. This CASE study performed an additional market study, which focused on the two following areas:

- Industry practices of multi-family building HVAC system designs
- Product availability and costs of wall furnaces and pipe insulation products

The study surveyed duct and pipe design practices to develop standard design improvements. Surveys on market penetration of different space heating systems provided the data needed for a statewide energy savings estimate.

The multi-family market practice survey was based primarily on the data available from the California Multifamily New Homes (CMFNH) programs. The CASE team reviewed HVAC designs of 167 buildings (77% Low-rise buildings and 23% high-rise buildings) located throughout California, built between 2008 and 2010. The sample included both affordable housing and market-rate apartment buildings. The broad range of participants in the CMFNH program was able to provide a market overview of system design practices for multi-family buildings. Utility multi-family programs do affect a large portion of the market and, especially under the current economic conditions, it is important to use the CMFNH database to capture the market trends. To the extent that these buildings participated in the CMFNH program, they were more energy-efficient than average new construction multi-family buildings, due to better equipment efficiency and building envelope performance. HVAC system designs of the participating building still reflect general market practices.

Costs of wall furnaces and pipe insulation materials were obtained from corresponding manufacturers and distributors.

3.2 Central DHW Distribution System and Hydronic Heating System ACM algorithms Improvement

ACM algorithms for recirculation distribution systems were developed based on findings from the PIER research on multi-family DHW distribution systems, which was also conducted by the Heschong Mahone Group (HMG). The CASE study improved the recirculation loop performance model developed by the PIER research and adapted the model into a set of algorithms suitable for compliance software implementation. The CASE further developed a performance model for branch pipes based on the heat transfer analysis method developed for recirculation loop modeling. Together with the recirculation loop model, a complete central DHW distribution system model was established.

In order to address the importance of distribution system piping designs, the CASE study investigated DHW recirculation system design practices. The CASE team reviewed building plans obtained from the PIER research field studies and those available from the CMFNH program. General design procedures for recirculation loop and branch piping were developed. This CASE study coordinated with the Pipe Sizing CASE study to develop a pipe sizing method specific to multi-family buildings. This CASE study also coordinated with the CASE study on Multi-family DHW System Improvement to investigate recirculation loop design optimizations. Based on these combined efforts, the CASE study developed a method to validate proposed recirculation loop designs and a standard recirculation loop design to promote efficient design practices.

The CASE study team also conducted detailed review of existing ACM rules for hydronic heating systems, especially combined hydronic heating systems, to verify if unnecessary compliance credits were provided by 2008 Title 24 to those systems.

3.3 Standard Designs Improvement

The CASE study focused on two areas of multi-family building space heating standard design improvements: air distribution duct assumptions and heating equipment efficiencies.

The investigation on air distribution duct designs was based on input provided by the CMFNH program implementers in HMG, who collectively had experiences working on more than one hundred multi-family projects. They brought up the issue of treatment of air duct loss in multi-family buildings, especially for buildings with hydronic heating. The CASE project team performed simulation studies using EnergyPro to identify specific issues in this area and developed the code change proposal according to multi-family building construction practices obtained from the market study.

The CASE project team carefully reviewed the Title 24 ACM to determine if proper heating system standard designs are defined for various proposed design scenarios. The corresponding sections of the Title 20 Appliance Efficiency Standards were also reviewed to verify if proper equipment efficiencies were used. In addition, the CASE study performed EnergyPro simulation studies to investigate how ACM rules are implemented. Two potential improvement opportunities were identified: using fan type wall furnaces as standard design when wall furnaces are used in proposed designs and using water heater boilers, instead of steam boilers, as the standard design equipment for hydronic space heating. The former was further investigated through cost effectiveness analysis while the latter was investigated through a feasibility study based on information collected by the market study.

3.4 Pipe Insulation Requirements

Pipe insulation improvement depends mostly on cost effectiveness of using thicker insulations. The CASE study investigated cost effectiveness of enhancing mandatory pipe insulation as prescribed in the 2008 Title 24 section 123 (Table 123-A) and expanding these requirements to pipes located in unconditioned buildings. The CASE study performed LCC analysis for different levels of insulation improvements to determine proposed changes.

3.5 Energy Savings Analysis

The proposed DHW recirculation loop performance algorithms will not directly generate any energy savings. It provides the necessary ACM rule sets required to implement the prescriptive requirements on recirculation system controls and piping designs, which are developed by the Multi-family DHW System Improvement CASE study.

For the proposed standard design changes, including air distribution ducts, wall furnace type, and hydronic heating boiler efficiency, energy savings were assessed based on simulation studies. For the low-rise multi-family building energy savings analysis, the CASE study used the CALRES along with its built-in multi-family model. EnergyPro was used for the high-rise multi-family building analysis. A high-rise multifamily EnergyPro model was developed based the same high-rise multi-family prototype used in the Multi-family DHW System Improvement CASE study. Configurations of two multi-family building prototypes are summarized in Figure 1.

Building Characteristics	CARRES Low-rise	High-rise Multi-family
Story	2	4
Number of Unit	8	86
Dwelling Unit Area (sf)	850	870

Figure 1 Building Prototypes for Energy Savings Analysis

Energy savings from potential pipe insulation improvement were estimated based on comparisons of pipe heat loss with different thickness of insulation. Pipe heat loss can be easier evaluated using conduction heat transfer equations.

3.6 Cost Estimates

The proposed DHW recirculation loop performance algorithms only provide a method to assess system energy consumptions and have no impact on design building construction and maintenance costs. The recommended changes of air distribution duct standard designs are intended to match standard designs with multi-family building physical constrains and, therefore, they will not trigger any building practice changes and cost increase. The following two areas of code changes will lead to construction cost increase:

- Improved pipe insulation
- Installation of fan type wall furnaces instead of gravity type wall furnaces

Costs for pipe insulation materials and wall furnaces were obtained from corresponding manufacturers and/or distributors.

3.7 Life Cycle Cost (LCC) Analysis

The CASE study performed life cycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2013 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = Cost\ Premium - Present\ Value\ of\ Energy\ Savings$$ [1]

$$\Delta LCC = \Delta C - (PV_{TDV\text{-}E} * \Delta TDV_E + PV_{TDV\text{-}G} * \Delta TDV_G)$$

Where:

ΔLCC	change in life cycle cost
ΔC	cost premium associated with the measure, relative to the base case
$PV_{TDV\text{-}E}$	present value of a TDV unit of electricity
$PV_{TDV\text{-}G}$	present value of a TDV unit of gas
ΔTDV_E	TDV of electricity
ΔTDV_G	TDV of gas

The LCC analysis used the 30-year natural gas TDV for both residential and nonresidential building prototypes. The useful life time of a type wall furnace was assumed to be 15 years, so cost premium for a fan type furnace was accounted twice within the 30 year period.

3.8 Statewide Energy Savings Estimate

Statewide space heating energy savings from standard design improvements were obtained by multiplying unit energy savings by the CEC's forecast on new constructions of multi-family and hotel/motel buildings. Peak demand savings were estimated as the average load (kW) reduction during summer peak hours, which are defined as 12 pm – 6 pm in July through September, according to CPUC treatment of demand savings for IOU energy efficiency programs. Statewide energy savings from pipe insulation requirement improvements were obtained by multiplying savings per unit pipe length by total pipe length in different affected categories.

3.9 Stakeholder Meetings

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at HVAC Stakeholder Meetings funded by the California investor-owned utilities (Pacific Gas and Electric, Southern California Edison, and Southern California Gas Company).

At each meeting, the utilities' CASE team asked for feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

[1] The Commission uses a 3% discount rate for determining present values for Standards purposes.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodesgroup.com. Stakeholder meetings were held on the following dates and locations:

- First NR HVAC Stakeholder Meeting: April 27, 2010, California Lighting Technology Center, Davis, CA
- Second NR HVAC Stakeholder Meeting: December 8, 2010, Webinar
- Third NR HVAC Stakeholder Meeting: April 8, 2011, Webinar

In addition to the Stakeholder Meetings, a Stakeholder Work Session covering hot water related requirements was held on October 4, 2010. CEC staff and multi and single family water experts attended this session.

4. Analysis and Results

This section describes detailed CASE study findings.

4.1 Market Study

Survey of multi-family building practices provided following findings on space heating system design issues related to this CASE study:

Hydronic heating systems, with either fan coil and radiant baseboard, are commonly used in multi-family buildings. Combined hydronic systems are mostly used in small multi-family buildings, including condominiums and townhouses, where dwelling units are served by individual water heaters for both DHW and space heating.

Air distribution ducts in multi-family buildings are mostly in conditioned spaces. This is obvious for dwelling units below the top story, since there are no unconditioned spaces between floors. For top stories, air distribution ducts, if installed, are typically not located in drop celling spaces, not in attic spaces. This is because top-story dwelling units are typically built the same way as units in lower stories, where a drop ceiling in kitchen or bathroom is used to host air ducts or fan coils.

The market study also provided market shares of different types of DHW and HVAC systems installed in multi-family buildings, as shown in Figure 2 and Figure 3. Figure 4 provide new construction forecasts for year 2014, which are used for statewide savings estimates.

Building Type	Low-rise	High-rise
Hydronic Heating	52%	67%
Split AC with Central Furnace	18%	3.5%
Split Heat Pump	28%	19%
Electric Baseboard	0%	3.5%
PTHP	1%	0%
Wall Furnace	1%	7%

Figure 2 Multi-family Building Space Heating Systems (% of new construction units)

Building Type	Low-rise	High-rise
Central DHW	82%	98%
Distributed DHW	18%	2%

Figure 3 Multi-family Building DHW Systems (% of new construction units)

Climate Zone	Low-rise (units)	High-rise (units)	Hotel/ Motel (million sqft)
1	94	0	0.034
2	684	140	0.290
3	863	1408	0.791
4	616	1583	0.769
5	269	158	0.149
6	1252	1593	0.500
7	1912	1029	0.672
8	1629	2249	0.943
9	1986	2633	2.191
10	2645	1029	0.330
11	820	81	0.166
12	2165	1701	1.337
13	1755	239	0.493
14	726	0	0.190
15	748	0	0.044
16	583	0	0.198
Total	**18748**	**13845**	**9.098**

Figure 4 New Construction Forecast for Year 2014 (unit/year)

4.2 Central DHW Distribution System and Hydronic Heating System ACM algorithms Improvement

4.2.1 DHW Recirculation System Performance Algorithms

The CASE study developed DHW recirculation system performance algorithms based on findings from the PIER research on distribution systems in multi-family central DHW systems. The PIER research performed field performance monitoring studies at more than thirty (30) multi-family buildings across California. Using an energy flow analysis method, the research found that the average overall central DWH system efficiency is only 34%. Distribution system heat losses represent about one third (1/3) of the total system energy consumptions, with recirculation loop heat loss being the dominant distribution heat loss component. Large energy savings can be achieved with improvement of recirculation system loop performance. The PIER research investigated energy savings from several recirculation loop control technologies. A recirculation loop performance model was developed to predict distribution system performance. These efforts were aimed to identify control technologies that could provide persistent energy savings and to develop recommendations on recirculation loop design improvement. However, at the end of the PIER research, the analysis on control technology savings could not provide definite savings estimate and the recirculation model could not be validated by field measurement data. The research on central DHW distribution system performance continued with support from two CASE studies. This CASE study focuses on distribution system model development and validation to support the development of ACM algorithms. The CASE study on Multi-family DHW System Improvement aims at developing specific improvement requirements. The two CASE studies are very closely correlated in that the new ACM algorithms and rules need to provide accurate energy savings estimates for involved technologies and recirculation loop designs and need to provide a compliance validation method.

Figure 5 illustrates a general central DHW system, which include a water heater system and a distribution network. A water heating system can include one or more water heaters or can include one or more boilers connected to a storage tank. Recirculation loops bring hot water to different parts of the building while distribution branches deliver hot water to individual fixtures. Distribution branches are further separated as in-unit branches and out-unit branches. The former are branch pipes inside dwelling units connect to end fixtures and the latter are pipes connecting in-unit branches to the recirculation loop. In-unit branch heat losses have the similar behavior as those in single-family homes and will be addressed by an IOU CASE study conducted by the Davis Energy Group. This CASE addresses recirculation loop and out-unit branch performance.

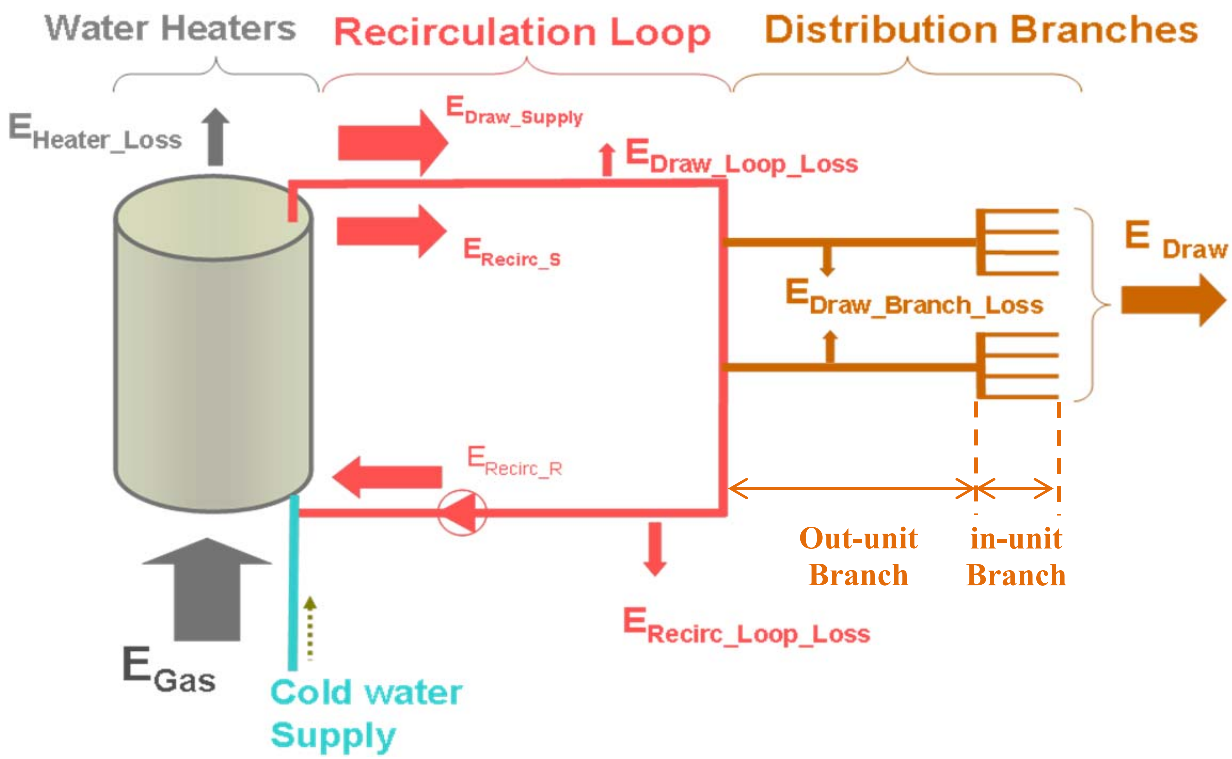


Figure 5 Schematics of a Central DHW System with One Recirculation Loop

Recirculation Loop Heat Loss Calculation Algorithms

Recirculation systems in actually buildings can be much more complicated than the one illustrated in Figure 5. Multiple recirculation loops might exist and one main recirculation loop may branch into several loops before merging back into one return path. The CASE study used actual recirculation loop design to perform recirculation model validation and improvement. Figure 6 shows one example of recirculation design studies by the CASE study. The Appendix A - Recirculation Loop Model Validation Results provides more examples with different types of recirculation loop designs. By validating model accuracy for different recirculation loop designs, the CASE study team could confidently use the model to study different design options to develop corresponding Title 24 requirements.

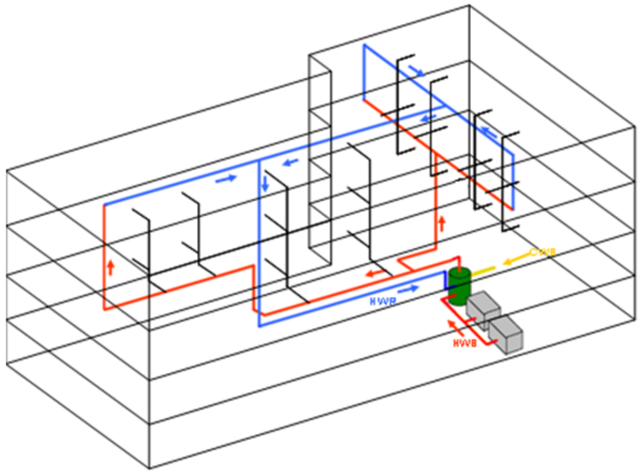


Figure 6 Example of an Installed DHW Recirculation Distribution Network

The PIER research concluded that recirculation pipe heat loss could be modeled with two basic modes: pipe heat loss with water flow and pipe heat loss without water flow. For a pipe section with a steady water flow inside, pipe heat loss can be calculated using the following equation, developed based on heat transfer analysis. The equation correlates heat loss with insulation condition, water flow rate, water temperature, and ambient temperature.

$$Q_{Loss,k} = \rho C_p V \cdot (T_{output,k} - T_{input,k})$$

$$T_{output,k} = (T_{input,k} - T_{amb,k}).e^{-\frac{UA_k}{\rho V c_p}} + T_{amb,k}$$

where

$T_{output,k}$	Temperature at the end of the pipe section k (◦F)
$T_{input,k}$	Temperature at the beginning of the pipe section k (◦F)
$T_{amb,k}$	Temperature of the pipe section k surroundings (◦F)
$\boldsymbol{UA_k}$	Heat transfer coefficient of the pipe section k (Btu/◦F.hr)
V	Hot water flow in the pipe section k (gph)
ρ	Water density (lb/gal)
$\boldsymbol{c_p}$	Water specific heat capacity (Btu/lb. ◦F)

Section k hot water input temperature is the output temperature of the previous pipe section *k-1*.

$$T_{input,k} = T_{output,k-1}$$

In the second pipe heat loss mode, there is no water flow and hot water will cool down. This is a transient process and heat loss depends on cool down time. The heat transfer model was developed based on the method of lumped capacity heat transfer analysis and the modeling formula is shown as below.

$$T_{input,k,n+1} = (T_{input,k,n} - T_{amb,k,n}).e^{-\frac{UA_k}{mc_p}.t} + T_{amb,k,n+1}$$

$$T_{output,k,n+1} = \left(T_{output,k,n} - T_{amb,k,n}\right).e^{-\frac{UA_k}{mc_p}.t} + T_{amb,k,n+1}$$

$$Q_{Loss,k,n} = m \cdot C_p \cdot (T_{k,n-1} - T_{k,n})$$

$T_{input,k,n+1}$	Temperature at beginning of the pipe section *k* at the end of the time step *n+1*(◦F)
$T_{input,k,n}$	Temperature at beginning of the pipe section *k* at the end of the time step *n* (◦F)
$T_{output,k,n}$	Temperature at the end of the pipe section *k* at the end of the time step *n+1*(◦F)
$T_{output,k,n+1}$	Temperature at the end of the pipe section *k* at the end of the time step *n* (◦F)
$T_{amb,k,n}$	Temperature of the pipe section *k* surroundings during the time step *n+1*(◦F)
UA_k	Heat transfer coefficient of the pipe section *k* (Btu/◦F.hr)
mc_p	Water and copper heat capacity of the pipe section *k* (Btu/ ◦F)

Practical recirculation loop operations can be modeled as a series of combinations of the two heat transfer modes depends on hot water draw and pump operation schedules. The PIER research did not have enough resources to complete the model development following this concept. The CASE study continued the PIER research efforts and developed an EXCEL based recirculation model following the above approach. Further validation of model accuracy were performed by comparing model prediction with measured recirculation performance under several system control operations. Figure 7 presents the model validation results for the building, of which the recirculation loop design is shown in Figure 6. It can be seen than the model can accurate predict overall system performance (DHW System Input Energy) as well as recirculation **loop** heat loss. Figure 7 also provides heat loss associated with recirculation flow, which is designated as recirculation **flow** heat loss and it part of the recirculation **loop** heat loss. This detailed level of heat loss calculation provided in-depth understanding of control technology performance and facilitated the development of system control requirements, addressed by the Multi-family DHW System Improvement CASE study. Validate results for other types of recirculation loop designs are provided in the Appendix A - Recirculation Loop Model Validation Results.

	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				DHW System Input Energy			
SFD	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**
CONT Pump	608,711	608,711	-	-	639,732	643,487	-	-	1,875,663	1,879,417	-	-
Temp Mod	600,697	582,695	1.3%	4.3%	633,433	616,266	1.0%	4.2%	1,958,764	1,941,597	-4.4%	-3.3%
Timer	507,048	461,656	17%	24%	600,803	562,822	6.1%	13%	1,732,428	1,694,446	7.6%	10%
Demand	215,483	191,328	65%	69%	411,903	453,556	36%	30%	1,423,628	1,465,281	24%	22%

Figure 7 Example of Recirculation Loop Performance Model Validation

The existing ACM algorithms for recirculation loop heat loss calculation were developed based on eQuest simulation studies. A set of empirical equations were developed based on simulation results to correlate pipe heat loss with recirculation pipe length, diameter, and ambient conditions. This method cannot differentiate performance of different designs and estimate savings from advanced controls.

The CASE study adapted the detailed recirculation model into a set of simplified ACM algorithms. First, each recirculation loop is represented with up to six pipe sections connected in sequence, with three sections for recirculation supply piping and three sections for return piping. This approach provides more flexibility in specify recirculation loop designs. Hourly heat loss calculation for each pipe section is a combination of the two heat transfer modes. The exact ratio of the two modes depends on schedules of pump operation and hot water supply temperature, which are controlled by recirculation controls. The control schedules can be further expanded in future to accommodate control technology improvements.

The existing DHW ACM algorithms rely on user input of recirculation loop pipe lengths to calculate pipe heat loss. If underestimated pipe length are provided, compliance software would underestimate recirculation loop heat loss. More importantly, since the standard design has the same recirculation loop configuration as the proposed design, the existing ACM cannot differentiate performance of different recirculation loop designs and, therefore, cannot promote efficient design practices. The CASE study proposes that the ACM include two sets of recirculation loop designs, a default design and a standard design. The default design represents typical design practices while the standard design represents an optimized design. The default design is also used to validate user input. If total recirculation loop surface area based on user inputs is smaller than that of the default design, a correction factor will be generated to correct heat loss calculation based on user input. Details of the default recirculation loop design are provided in section 5**Error! Reference source not found.**, proposed ACM language changes to Residential ACM Appendix E. The standard design is developed the Multi-family DHW System Improvement CASE study.

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

Figure 8 Distribution Pipe Sizing Table

The default design includes a simply recirculation loop located on a middle floor. Necessary pipe runs are added for connecting the main loop to water heaters located on the first floor or on the top floor. This default design is more streamlined than most recirculation loop designs observed during PIER research field studies and, therefore, it provides a good reference for minimum recirculation loop length. For developing the default design, the CASE study coordinated with the Pipe Sizing CASE study to develop a procedure for distribution system pipe sizing. Each multi-family dwelling unit is assumed to have one kitchen sink, one bath sink, and one shower/tub combo. Following the 2009 Uniform Plumbing Code (UPC), a correlation table was produced between distribution pipe diameter and number of dwelling units served by the distribution pipe. The results are shown in Figure 8. The correlated was further summarized into one equation, as shown below, for easy implementation by the Title 24 ACM.

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

where

Dia Pipe diameter (inch)

Unit Number of dwelling unit

Out-unit Branch Heat Loss

Branch pipe heat losses behave drastically differently from recirculation loop heat losses for two reasons. First, presence of hot water in branch pipes depends on hot water draw schedules. Second, there is water and energy loss associated with filling branch pipe with hot water for the first draw after pipes are cooled down. As a result, branch pipe heat loss include two modes, heat loss during hot water usage and heat loss due to water waste. They are modeled as following for each branch line:

$$\text{Hourly heat loss during usage} = (\text{Hourly Building Hot Water Draw/Number of Branch}) \cdot \rho_{water} \cdot Cp \cdot \Delta T_{branch}$$

$$\text{Hourly heat loss due to water waste} = N_{waste} \cdot SCH \cdot \rho_{water} \cdot Cp \cdot (f_{vol} \cdot Vol_{branch}) \cdot (T_{supply,branch} - T_{coldwater})$$

where

ΔT_{branch} Temperature drop along the branch line. It can be calculated in the same way as recirculation pipe heat loss with flow.

N_{waste} Number of times in a day for which water is dumped before use.

SCH Hourly water waste schedule.

f_{vol} The multiplier to account for increased water waste due to branch pipe heating, imperfect mixing, and user behaviors. It is assumed to be 1.4.

$T_{supply,branch}$ Average branch input temperature (^oF).

$T_{coldwater}$ The cold water inlet temperature (^oF)

The hourly heat loss due to water waste reflects the thermal energy associated with water that is dumped before actual use. The amount of water wasted is more than just the internal volume of a branch pipe. A multiplier, f_{vol} =1.4, was used to include the following effects:

- About 10% of the hot water is need to warm up the branch pipe
- Stratified flow that cause additional hot water waste
- Users do not constantly monitor hot water temperature and lead to extra hot water waste

The number of waiting for each hour depends on the hot water usage schedule, which further depends on the number of dwelling units connected to the branch. In order to obtain general hot water draw patterns, the CASE study used a tool developed by the National Renewable Energy Laboratory (NREL), which generate random hot water draw events based on residential building hot water draw statistics obtained from multiple field studies. Each dwelling unit was assumed to have one bath room and one kitchen. Using the NREL tool, random hot water draw events were generated for one year for each dwelling unit and collective hot water draws were obtained by combining draw events of all connected dwelling units. By tracking time delays between draw events, the branch pipe temperature were tracked using the pipe cool-down heat transfer equation. Once the branch pipe temperature was cooled to below 85^{o}F, it was deemed that water in pipe would be dumped for the next draw.

Figure 9 presents the correlation between the number of times water been dumped before uses to the number of dwelling units connected to the branch. In addition, the study also summarized the number of water waste during different hours of the day to provide the hourly schedule of water waste. The results are shown in Figure 10. These results were incorporated into the proposed ACM changes.

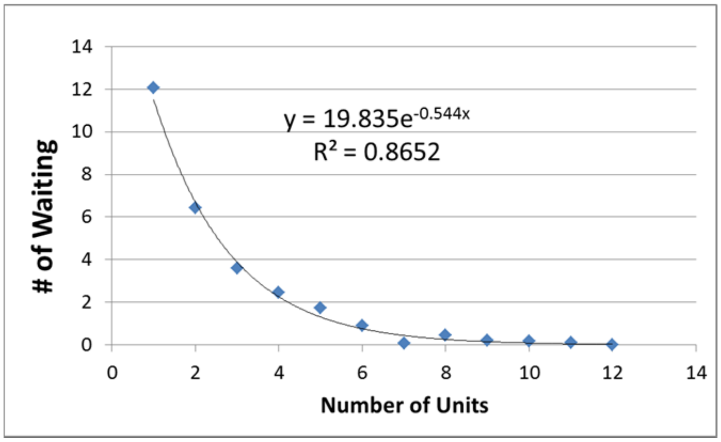


Figure 9 Daily Number of Branch Cool Down per Day vs. Number of Dwelling Units

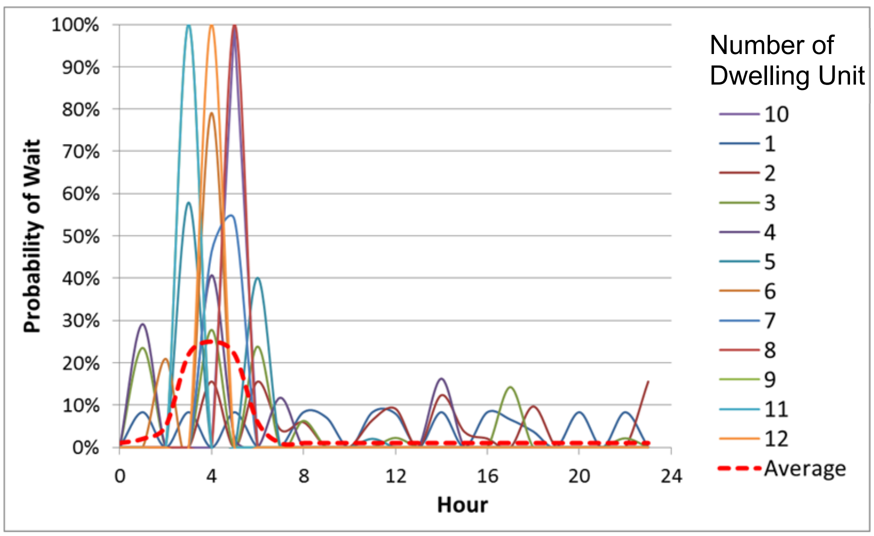


Figure 10 Hourly Probability of Pipe Cool-down

4.2.2 Hydronic Heating System

Recirculation loop pipe heat losses in hydronic heating systems are due to the same heat transfer mechanisms as those for DHW recirculation loop heat losses. The ACM algorithms discussed in the last section for DHW systems can be applied to hydronic heating systems, if the recirculation loop configurations are known. If all pipe heat losses within conditioned spaces are considered as meeting space heating loads, the calculation can be simplified without knowing piping configuration information within conditioned spaces. Figure 11 illustrates this concept that the hourly space heating load can be used to calculate the hot water return temperature, which determines the return pipe heat losses.

However, this simplified treatment of pipe heat loss in conditioned space does not truly reflect practical building operations. When outdoor temperatures are mild, a building does not call for heat all the time, but distribution loops are kept warm all the time, though at lower temperatures. In this case, pipe heat losses should be considered as a waste. This loss can be much more significant than pipe heat losses in unconditioned spaces, especially for large buildings and buildings in mild climate zones. In order to properly account for this heat loss effect, more detailed investigation of hydronic system operations is needed, which is out of the scope of this CASE study.

The 2008 Title 24 residential ACM includes a formula to approximate hourly pipe heat losses in unconditioned spaces for combined hydronic space heating and water systems (Residential ACM section 5.3 Combined Hydronic Space/Water Heating). The simplified treatment of pipe heat loss, as illustrated in Figure 11 will provide little improvement to the existing requirement. Therefore, the CASE study team decided not to recommend any changes to the existing hydronic heating pipe heat loss calculations.

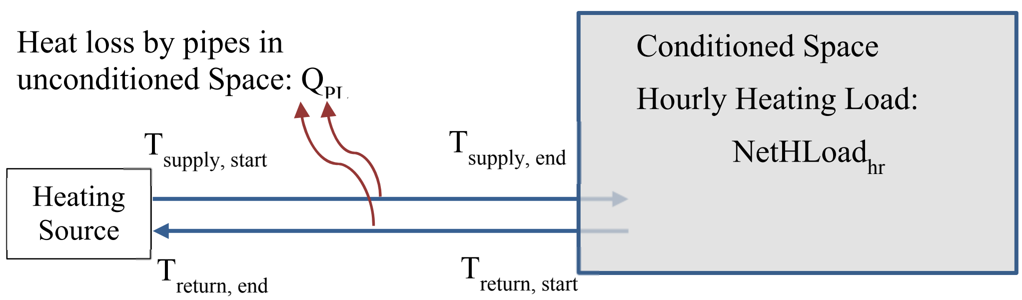


Figure 11 Schematics of Pipe Heat Loss in Hydronic Heating Systems

4.3 Standard Design Improvement

4.3.1 Air Distribution Duct

The CASE study market study indicated that the air distribution ducts in multi-family buildings, if installed, were mostly located in conditioned spaces. This design practice is not fully reflected in the Title 24 residential and nonresidential ACMs, especially when the proposed heating system is a hydronic heating system.

Standard system designs for low-rise multi-family buildings are defined in the Table R3-30 in the 2008 Title 24 Residential ACM. Hydronic heating systems and combined hydronic systems fall into the “All other gas heating” category and the corresponding standard design is “Split system air conditioner with gas furnace and air distribution ducts”. Duct location and efficiency are treated in the same way as single family homes, according to the Table R3-31. This treatment provides an unnecessary energy budget associated with duct leakage losses, even for dwelling unit in low floors. Effectively, a compliance credit is provided to hydronic heating and combined hydronic heating systems. In the same way, unnecessary duct loss credits are provided to proposed designs belong to the “Any other electric heat including electric resistance, water source heat pump, etc.” category.

In order to remove the unnecessary duct loss credit, multi-family building standard designs and proposed designs should have the same duct configuration. This can be done by modifying the corresponding standard design entries in the Table R3-30 to include the following language:

“For multi-family buildings, air distribution duct in the standard design shall have the same configurations as those in the proposed design.”

In the 2008 Title 24 Nonresidential ACM, HVAV system standard designs provided in the Table N2-13 are most according to proposed cooling systems. In heating dominated climate zone, it is very common for multi-family buildings to only have space heating without space cooling equipment. When a hydronic heating system is installed without any cooling equipment, the proper choice of cooling equipment should be “Hydronic”. This would ensure that the corresponding standard design is the System #5, defined as a four-pipe fan coil system with central plant. The cooling system is modeled with no cooling capacity so that there is no impact to compliance margin. However, it is very likely that other cooling system is selected as the proposed design since no cooling systems will be installed. The corresponding standard design is System #1, defined as a packaged single zone system, which include an energy budget for air duct distribution losses. Effectively, an unrealistic compliance credit would be given to hydronic heating systems.

To correct this problem, we recommend that the ACM descriptions for System #1 should include the following language for duct efficiency specification:

“For All residential including hotel/motel guest room, the standard design and the proposed design shall use the same duct system efficiency.

4.3.2 Wall Furnace

There are two types of wall furnace available in the market, fan type and gravidity type. Fan type wall furnaces use a built-in fan to enhance air circulation, therefor, have higher efficiencies than gravity type furnaces. Both types of wall furnaces are regulated by federal energy efficiency standards and minimum AFUE standards are summarized in Figure 12. Since fan type wall furnaces are much more efficient than gravity types, it is desirable to set fan type wall furnaces as the standard design when wall furnaces are used as the proposed heating equipment, Both types of wall furnaces are widely available. The following sections will provide cost effectiveness analysis of fan type wall furnaces, with gravity type wall furnaces as the baseline.

Type	Capacity (Btu per hour)	Minimum AFUE (%)
Fan	≤ 42,000	73
Fan	> 42,000	74
Gravity	≤ 10,000	59
Gravity	> 10,000 ≤ 12,000	60
Gravity	> 12,000 ≤ 15,000	61
Gravity	> 15,000 ≤ 19,000	62
Gravity	> 19,000 ≤ 27,000	63
Gravity	> 27,000 ≤ 46,000	64
Gravity	> 46,000	65

Figure 12 for Wall Furnace Minimum Efficiency Standards

4.3.3 Boiler Efficiency for Hydronic Heating Systems

Most hydronic heating systems use hot water boilers instead of steam boilers to provide hot water for space heating. Therefore, standard designs shall be based on hot water boils, which, in general, are more efficiency than steam boilers. In the Nonresidential ACM, descriptions for System #3, #4, and #5, which use boiler as heating equipment, only specify the heating system as gas boiler, without specifying the boiler type. In EnergyPro, boiler efficiency for the standard design is equal to the federal minimum efficiency standard for steam boilers, AFUE =75%, while federal minimum efficiency standard for gas hot water boiler is AFUE =80%.

The CASE study recommends to revise the corresponding ACM language to specify gas hot water boiler as the standard design heating equipment.

4.4 Pipe Insulation Requirements

Mandatory pipe insulation requirements for hot water and space heating systems are provided in the 2008 Title 24 section 123 Table 123-A, as shown in Figure 13. With the updated TDV values, the CASE study evaluated the cost effectiveness of requiring thicker insulations for each space and water application in Figure 13.

Fluid Temperature Range (°F)	**Conductivity Range (Btu-inch/hr/ sqft/ °F)**	**Nominal Pipe Diameter (inches)**					
		Runouts up to 2	**1 and less**	**1.25 - 2**	**2.5-4**	**5 - 6**	**8 and larger**
		Insulation Thickness Required (inches)					
Space heating systems							
Above 350	0.32-0.34	1.5	2.5	2.5	3	3.5	3.5
251-350	0.29-0.31	1.5	2	2.5	2.5	3.5	3.5
201-250	0.27-0.30	1	1.5	1.5	2	2	3.5
141-200	0.25-0.29	0.5	1.5	1.5	1.5	1.5	1.5
105-140	0.24-0.28	0.5	1	1	1	1.5	1.5
Service water-heating systems							
Above 105	0.24-0.28	0.5	1	1	1.5	1.5	1.5
Space cooling systems (chilled water, refrigerant and brine) – no proposed change by this CASE study							
40-60	0.23-0.27	0.5	0.5	0.5	1	1	1
Below 40	0.23-0.27	1	1	1.5	1.5	1.5	1.5

Figure 13 2008 Title 24 Insulation Requirements and Proposed Improvements

The 2008 Title 24 section 123 is only applicable to pipes located in conditioned buildings, according to section 100 Table 100-A. The CASE study will demonstrate that pipe insulation in unconditioned spaces is cost effective and, therefore, recommend section 123 be applicable to all building types and Table 123-A be applicable to process heating systems.

4.5 Energy Savings Analysis

The proposed ACM algorithm changes for DHW recirculation systems will not introduce any direct energy savings, since the performance calculation method itself will not affect code requirement stringencies. A parallel CASE study, Multi-family DHW Improvement CASE Study, will propose prescriptive requirements on central DHW system control and piping design, which will provide energy savings by improving recirculation system efficiencies. The proposed ACM changes developed by this CASE study are essential to implement those prescriptive requirements.

Energy savings for proposed standard design changes were assessed based on building energy simulation studies. Two prototype multi-family buildings are used for analysis and their characteristics are summarized in Figure 1.The CASE study used the CALRES to analyze energy savings from the low-rise multi-family prototype and used the EnergyPro for the high-rise prototype savings analysis. Models for both prototypes were set to be compliant with 2008 Title 24 before further savings analysis.

4.5.1 Air Distribution Duct

For the low-rise prototype, we investigated the compliance margin of a proposed design using hydronic heating. The boiler efficiency was set to be 80% AFUE, which is equivalent to the central furnace recovery efficiency of 80% used for the standard design. The difference in building annual heating energy between the proposed and the standard designs represents the energy savings from removing the unnecessary duct loss credit. The results are shown in Figure 14 for all sixteen (16) climate zones.

For high-rise prototype analysis using EnergyPro, the proposed system design was set have a split DX system with hot water heating. The distribution system was configured as a ducted system with default duct configurations. Cooling capacity was set to be zero to represent the no-cooling condition. Boiler efficiency was set to be 80% AFUE to match with the standard design central furnace efficiency. The proposed design had less annual heat energy consumption than the standard design because the standard design included duct heat loss. The different of represent energy savings that can be achieved by removing the duct loss credit for high-rise multi-family buildings. The results are shown in Figure 14.

Climate Zone	Annual Energy Savings (Therm/Building)		Annual Energy Savings (Therm/Dwelling Unit)	
	Low-Rise	High-Rise	Low-Rise	High-Rise
1	114.4	789	14.3	9.0
2	162.0	1071	20.3	12.2
3	71.7	297	9.0	3.4
4	103.7	572	13.0	6.5
5	82.4	274	10.3	3.1
6	25.8	45	3.2	0.5
7	18.9	24	2.4	0.3
8	32.0	86	4.0	1.0
9	30.5	59	3.8	0.7
10	54.3	194	6.8	2.2
11	148.0	1293	18.5	14.7
12	130.4	1011	16.3	11.5
13	94.1	815	11.8	9.3
14	144.7	1242	18.1	14.1
15	14.3	75	1.8	0.9
16	319.0	2356	39.9	26.8

Figure 14 Energy Savings - Change of Air Distribution Duct Standard Design

4.5.2 Wall Furnace

The potential wall furnace standard design improvement would only be applicable to residential ACM and, therefore, low-rise multi-family buildings. The CASE study compared difference in annual heating energy consumption using two different wall furnace efficiencies, AFUE = 73% and AFUE = 62%, which represent efficiencies of fan type and gravity wall furnaces. Figure 15 presents annual site energy and TDV energy savings for each dwelling unit, where one wall furnace is installed.

Climate Zone	Annual Heating Energy Savings (Therm/Dwelling Unit)	TDV Heating Energy Savings (kBtu/Dwelling Unit)
1	8.7	1226
2	0.11	1309
3	0.048	591
4	0.056	694
5	0.025	307
6	0.004	50
7	0.002	21
8	0.008	100
9	0.004	51
10	0.021	256
11	0.120	1487
12	0.11	1394
13	0.088	1093
14	0.12	1466
15	0.007	93
16	0.27	3325

Figure 15 Energy Savings – Fan Type Wall Furnace

4.5.3 Boiler for Hydronic Space Heating

The proposed clarification of using hot water boiler, not steam boiler, will only affect high-rise multi-family building. New federal boiler efficiency standards will take effect in September 1, 2012, before the projected effective date for 2013 Title 24. The new standards require minimum efficiency of 80% AFUE for steam boilers and 82% AFUE for hot water boilers. The CASE study compared building heating energy consumptions using the two energy efficiency values. The difference represents the energy savings to be achieved by changing the standard design from a steam boiler to a hot water boiler. The results are shown in Figure 16.

Climate Zone	Annual Energy Savings (Therm/Building)	Annual Energy Savings (Therm/Dwelling unit)
	High-Rise	**High-Rise**
1	96	1.09
2	102	1.16
3	47	0.53
4	54	0.61
5	24	0.27
6	3.91	0.04
7	1.62	0.02
8	7.84	0.09
9	4	0.05
10	20.0	0.23
11	116	1.32
12	109	1.24
13	85	0.97
14	115	1.30
15	7.24	0.08
16	260	2.95

Figure 16 Energy Savings – Change of Standard Design Boiler Efficiency

4.5.4 Pipe Insulation

Energy savings from pipe insulation improvements were estimated by comparing pipe heat loss before and after insulation improvement. Pipe heat losses were estimated using the following equation:

$$Q_{loss} = UA_{pipe} \cdot (T_{fluid} - T_{Amb})$$

where

Q_{loss}: Pipe heat loss per unit length of pipe (Btu/ft)

UA_{pipe}: Heat transfer rate for unit length of pipe (Btu/ft)

T_{fluid}: Temperature of fluid (water or stream) inside the pipe (°F)

T_{Amb}: Ambient temperature (°F)

The calculation of UA_{pipe} included insulation conduction, surrounding air free convection, and radiation. With insulation, insulation conduction dominates the overall heat loss rate.

The CASE study investigated two improvement opportunities. The first opportunity is to increase pipe insulation thickness by half inch, for mandatory requirements prescribed in the 2008 Title 24 Section 123 Table 123-A, if the existing insulation thickness requirement is less than 3.5 inches. The baseline for energy savings assessment is the existing mandatory insulation requirements. Energy savings correspond to reduced heat loss due to thicker insulations. For T_{fluid}, we used the average temperatures for each temperature range listed in the Table 123-A. For DHW systems, T_{fluid} was assumed to be 130°F. Ambient temperature, T_{Amb}, was assumed to be indoor drybulb temperature of 68°F and, therefore, energy savings are the same for all climate zones. Figure 17 and Figure 18 present results for annual site energy savings and TDV energy savings, assuming pipes are used all year round.

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (Therm/ft/yr)									
Above 350	0.32-0.34	0.52	0.66	0.18	0.21	0.30	0.26	0.39	0.00	0.00	0.00
251-350	0.29-0.31	0.31	0.39	0.19	0.16	0.22	0.27	0.40	0.00	0.00	0.00
201-250	0.27-0.30	0.32	0.42	0.19	0.22	0.32	0.25	0.37	0.71	0.53	0.00
141-200	0.25-0.29	0.49	0.65	0.12	0.14	0.20	0.24	0.36	0.00	0.52	0.52
105-140	0.24-0.28	0.22	0.29	0.11	0.13	0.18	0.22	0.34	0.00	0.27	0.27
DHW >105	0.24-0.28	0.25	0.33	0.12	0.14	0.21	0.14	0.21	0.00	0.31	0.31

Figure 17 Energy Savings - Pipe Insulation Improvement in Conditioned Buildings

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (TDV KBtu/ft/yr)									

Above 350	0.32-0.34	87	112	30	35	50	45	66	0	0	0
251-350	0.29-0.31	51	66	32	27	38	45	67	0	0	0
201-250	0.27-0.30	70	91	25	30	44	41	62	57	89	46
141-200	0.25-0.29	83	109	20	23	34	40	61	74	88	88
105-140	0.24-0.28	37	48	18	21	31	38	57	51	45	45
DHW >105	0.24-0.28	42	55	20	24	35	24	36	44	52	52

Figure 18 TDV Energy Savings - Pipe Insulation Improvement in Conditioned Buildings

The second opportunity is to require the same mandatory pipe in unconditioned buildings. We performed the energy savings analysis using the same insulation thickness Discussed above. The baseline for energy savings calculation is un-insulated pipes, since pipe insulation in unconditioned buildings is not required. Ambient temperatures, T_{Amb} were obtained from the updated weather files for 2013 Title 24. Energy savings depend on climate zones, since each climate zone has different ambient temperature. Both averages savings over all climate zones and the lowest energy savings (climate zone 15) are presented. Figure 19 and Figure 20 show annual site energy savings and TDV energy savings, respectively, averaged over all sixteen climate zones. Figure 21 and Figure 22 show annual site energy savings and TDV energy savings, respectively, for climate zone 15, which has the lowest savings among all sixteen climate zones.

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (Therm/ft/yr)									
Above 350	0.32-0.34	6.4	8.7	11.0	13.2	19.6	23.9	35.1	41.4	48.2	48.2
251-350	0.29-0.31	5.3	7.3	9.2	11.2	16.6	20.0	29.4	35.1	40.9	40.9
201-250	0.27-0.30	3.6	5.0	6.2	7.5	11.1	13.7	20.2	23.7	27.8	28.5
141-200	0.25-0.29	2.5	3.3	4.2	5.1	7.5	9.1	13.4	15.5	18.4	18.4
105-140	0.24-0.28	1.4	1.8	2.3	2.8	4.1	5.0	7.4	8.8	10.5	10.5
DHW >105	0.24-0.28	1.5	2.1	2.6	3.1	4.7	5.8	8.5	9.9	11.8	11.8

Figure 19 Site Energy Savings - Pipe Insulation in Unconditioned Buildings (average)

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (TDV KBtu/ft/yr)									
Above 350	0.32-0.34	1076	1475	1863	2240	3320	4046	5945	7007	8146	8146
251-350	0.29-0.31	899	1229	1552	1893	2804	3380	4978	5946	6918	6918
201-250	0.27-0.30	516	705	889	1069	1584	1932	2850	3328	3927	3982
141-200	0.25-0.29	417	569	717	862	1278	1541	2275	2641	3137	3137
105-140	0.24-0.28	231	316	399	479	710	857	1265	1514	1797	1797
DHW >105	0.24-0.28	259	354	446	536	795	986	1457	1695	2012	2012

Figure 20 TDV Energy Savings - Pipe Insulation in Unconditioned Buildings (average)

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (Therm/ft/yr)									
Above 350	0.32-0.34	6.04	8.28	10.46	12.58	18.64	22.72	33.39	39.35	45.74	45.74
251-350	0.29-0.31	4.99	6.82	8.61	10.50	15.56	18.75	27.62	33.00	38.39	38.39
201-250	0.27-0.30	3.30	4.51	5.70	6.85	10.15	12.48	18.41	21.57	25.35	25.96
141-200	0.25-0.29	2.45	3.35	4.22	5.07	7.51	9.06	13.38	15.53	18.45	18.45
105-140	0.24-0.28	1.03	1.41	1.78	2.14	3.17	3.83	5.65	6.76	8.03	8.03
DHW >105	0.24-0.28	1.20	1.63	2.06	2.48	3.68	4.56	6.74	7.83	9.30	9.30

Figure 21 Site Energy Savings - Pipe Insulation in Unconditioned Buildings (CZ15)

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		Annual Energy Savings (TDV KBtu/ft/yr)									
Above 350	0.32-0.34	1028	1409	1780	2140	3171	3865	5679	6694	7781	7781
251-350	0.29-0.31	850	1162	1467	1789	2650	3195	4705	5621	6539	6539
201-250	0.27-0.30	516	705	889	1069	1584	1932	2850	3328	3927	3982
141-200	0.25-0.29	417	569	717	862	1278	1541	2275	2641	3137	3137
105-140	0.24-0.28	181	247	312	375	556	670	990	1184	1406	1406
DHW >105	0.24-0.28	209	285	360	432	641	795	1174	1366	1621	1621

Figure 22 TDV Energy Savings - Pipe Insulation in Unconditioned Buildings (CZ15)

4.6 Cost Estimates

Both wall furnaces and pipe insulation materials are commodity products. Their costs were obtained from manufacturers and distributors. Figure 23 presents costs of the two types of wall furnaces. The average different is $514/unit.

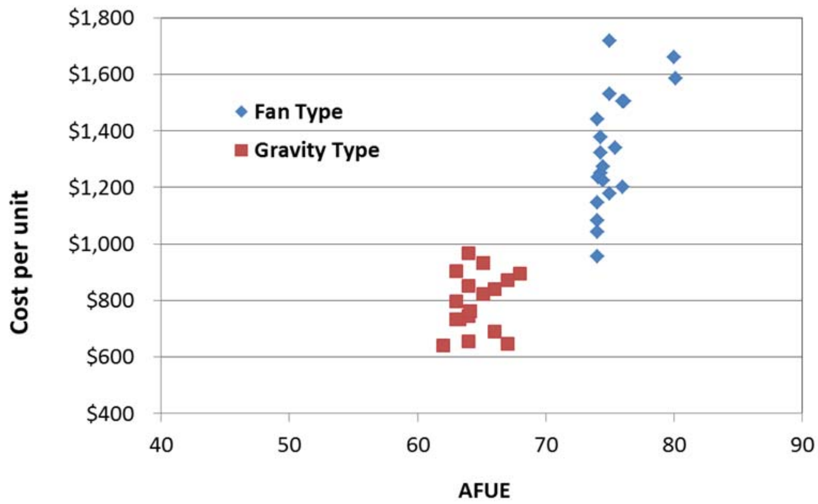


Figure 23 Wall Furnace Costs

Figure 24 presents pipe insulation material costs for different pipe diameter and thickness. For new pipe insulation installation, the labor cost is estimated to be $0.70 per foot of pipe. No additional labor cost is needed for installing a thicker insulation.

Pipe Diameter (inch)	Insulation Thickness (inch)		
	1	1.5	2
1	$2.68	$5.05	$8.05
2	$3.70	$6.78	$9.97
3	$5.89	$7.62	$11.40
4	$9.14	$8.68	$13.28

Figure 24 Pipe Insulation Material Cost ($/ft)

4.7 Life Cycle Cost (LCC) Analysis

LCC analysis was performed for two of the proposed changes, improved insulation requirements and standard designs for wall furnaces, which would introduce additional building construction costs. All other proposed ACM algorithm and standard design changes do not directly require any building practices adjustment. They simply improve accuracy of building energy consumption calculations, therefore, they do not require LCC analysis.

The following LCC analysis results were based on the method provide in section 3.7, energy savings estimates from section 4.5, and cost estimates from section 4.6. Negative LCC values indicate the corresponding change are cost effective.

4.7.1 Fan Type Wall Furnace

Based on the TDV energy savings provided in Figure 15, present values of energy savings were calculated using the residential 30-year PV adjustment factor (0.173 $/TDV kBtu). The incremental cost of a fan type wall furnace was estimated to be $514, compared to a gravity type wall furnace. Following the cost effectiveness analysis method provided in 3.7, LCC of fan type wall furnaces was evaluated and the results are shown in Figure 25. Only in climate zone 16, where building annual heating loads are relatively high, the fan type wall furnace can provide positive life cycle savings. With the consideration of additional cost for electrical wiring, fan type wall furnace is barely cost effective in climate zone 16. Therefore, the CASE study team decided not to propose changes to the existing wall furnace standard design.

Climate Zone	PV Energy Savings ($/dwelling unit)	Incremental Wall Furnace Cost ($/dwelling unit)	LCC ($/dwelling unit)
1	$212	$514	$302
2	$227	$514	$287
3	$102	$514	$412
4	$120	$514	$394
5	$53	$514	$461
6	$9	$514	$505
7	$4	$514	$510
8	$17	$514	$497
9	$9	$514	$505
10	$44	$514	$470
11	$257	$514	$257
12	$241	$514	$273
13	$189	$514	$325
14	$254	$514	$260
15	$16	$514	$498
16	$576	$514	-$62

Figure 25 LCC – Fan Type Wall Furnace

4.7.2 Pipe Insulation

Cost effectiveness of pipe insulation improvement was analyzed based on energy savings provided in section 4.5.4 and insulation costs in section 4.6. In section 4.5.4, annual energy savings were calculated based on the assumption that pipes would be at operating temperatures all year round. For DHW system, this assumption is accurate since continuous DHW services are expected in most buildings. Space heating is only needed during winter seasons. Duration of heating seasons varies by climate zones.

For increasing existing pipe insulation thickness requirements by half inch, we assumed space heating services were provided for 50% of a year and DHW services were provided for 100% of a year. Present value of energy savings and life cycle costs are shown in Figure 26 and Figure 27, respectively. It can be seen that increasing DHW system pipe insulation has negative LCC and, therefore, is cost effective. However, increasing space heating system pipe insulation was found to be not cost effective for most cases. As a result, the CASE study will not propose increased insulation thickness for pipes in space heating systems.

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		PV Savings ($/ft) – 30 year gas TDV									
Above 350	0.32-0.34	$13.5	$17.2	$4.6	$5.4	$7.7	$6.9	$10.1	$0.0	$0.0	$0.0
251-350	0.29-0.31	$7.9	$10.2	$4.9	$4.1	$5.8	$7.0	$10.3	$0.0	$0.0	$0.0
201-250	0.27-0.30	$10.7	$14.0	$3.9	$4.6	$6.7	$6.4	$9.6	$8.8	$13.8	$0.0
141-200	0.25-0.29	$12.8	$16.8	$3.0	$3.6	$5.2	$6.2	$9.4	$11.5	$13.5	$13.5
105-140	0.24-0.28	$5.6	$7.5	$2.7	$3.3	$4.8	$5.8	$8.8	$7.9	$7.0	$7.0
DHW >105	0.24-0.28	$6.4	$8.5	$3.1	$3.7	$5.5	$3.7	$5.5	$6.7	$8.0	$8.0

Figure 26 PV Savings - Pipe Insulation Improvement in Conditioned Buildings

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		LCC ($/ft) – 30 year gas TDV									
Above 350	0.32-0.34	-$2.3	-$4.2	$2.1	$1.7	$0.8	$2.0	$0.9	$0.00	$0.0	$0.0
251-350	0.29-0.31	-$0.3	-$1.4	$1.3	$2.4	$1.7	$1.3	$0.2	$0.00	$0.0	$0.0
201-250	0.27-0.30	-$2.4	-$4.0	$1.1	$0.8	$0.0	$1.0	$0.0	$0.81	-$1.2	$0.0
141-200	0.25-0.29	-$3.4	-$5.4	$1.5	$1.3	$0.8	$0.5	-$0.5	-$1.1	-$1.7	-$0.8
105-140	0.24-0.28	-$0.6	-$1.5	$1.0	$0.8	$0.4	$0.1	-$0.7	$0.43	$1.60	$2.45
DHW >105	0.24-0.28	-$4.2	-$6.2	-$0.8	-$1.3	-$2.7	-$0.1	-$1.3	-$2.1	-$2.9	-$2.1

Figure 27 LCC - Pipe Insulation Improvement in Conditioned Buildings

Pipe insulation in unconditioned buildings was approved to be cost effective. As shown in Figure 28 and Figure 29, even in climate zone 15, where energy savings are the lowest and pipes were assumed to be in use for 15% time of a year, LCC values are negative. Based on these LCC results, the CASE study recommends that mandatory pipe insulation be applied to pipes in unconditioned buildings.

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		PV Savings ($/ft) – 30 year gas TDV									
Above 350	0.32-0.34	$158	$217	$274	$330	$488	$595	$875	$1,031	$1,198	$1,198
251-350	0.29-0.31	$131	$179	$226	$276	$408	$492	$725	$866	$1,007	$1,007
201-250	0.27-0.30	$79	$109	$137	$165	$244	$298	$439	$512	$605	$613
141-200	0.25-0.29	$64	$88	$110	$133	$197	$237	$350	$407	$483	$483
105-140	0.24-0.28	$28	$38	$48	$58	$86	$103	$152	$182	$217	$217

Figure 28 PV Savings - Pipe Insulation in Unconditioned Buildings (CZ15) – 15% duty

Fluid Temperature Range (°F)	Conductivity Range (Btu-inch/hr/ sqft/ °F)	Nominal Pipe Diameter (inches)									
		0.5	0.75	1	1.25	2	2.5	4	5	6	8
		LCC ($/ft) – 30 year gas TDV									
Above 350	0.32-0.34	-$8	-$17	-$25	-$33	-$55	-$64	-$101	-$122	-$144	-$138
251-350	0.29-0.31	-$9	-$15	-$22	-$25	-$43	-$54	-$85	-$97	-$115	-$109
201-250	0.27-0.30	-$5	-$9	-$12	-$16	-$27	-$30	-$47	-$56	-$68	-$50
141-200	0.25-0.29	-$2	-$5	-$8	-$11	-$20	-$25	-$39	-$46	-$55	-$52
105-140	0.24-0.28	$0	-$1	-$2	-$3	-$6	-$8	-$14	-$12	-$15	-$12

Figure 29 LCC - Pipe Insulation in Unconditioned Buildings (CZ15) - 15% duty

4.8 Statewide Energy Savings Estimate

Statewide energy savings were estimated for following code change recommendations:

- Remove duct loss credit for low-rise and high-rise multi-family building
- Increase standard design boiler efficiency from 80% AFUE to 82% AFUE
- Pipe insulation improvements
    1. Increase DHW recirculation pipe thickness by ½ inch
    2. Require DHW recirculation branch pipes to be insulated
    3. Require pipe insulation in unconditioned buildings

Unit energy savings have been provided for all above measures have been provided in Section 4.5 Energy Savings Analysis. Figure 30 summarizes the building types and precentages of new construction buildings that are affected these measures. The percentages were determined by market penetration of applicable systems, which are provided in Figure 2 and Figure 3.

Measure	Building Type	System Type	% of New Construction
Air Duct Credit	Low-Rise MF	Hydronic heating system Split AC with central gas furnace	70%
	High-Rise MF	Hydronic heating system	67%
Boiler Efficiency	High-Rise MF	Hydronic heating system	67%
Pipe Insulation	Low-Rise MF	Central DHW with recirculation	82%
	High-Rise MF	Central DHW with recirculation	98%
	Hotel/Motel	Central DHW with recirculation	98%
	Unconditioned Building	Systems with hot water/steam pipes	100%

Figure 30 Buildings Affected by the Proposed Measures

For the air distribution duct and boiler efficiency measures, energy savings per dwelling unit are provided in Figure 14 and Figure 16, respectively, for each climate zone. Low-rise and high-rise new construction rate forecasts for each climate zone are provided in the Figure 4. Using the percentages provided in Figure 30, we estimated the number of new construction multi-family units that are subject to the proposed measures. Natural gas energy savings were calculated for each climate zone and summed together to obtain statewide energy savings. The results are shown in Figure 32.

For the pipe insulation measure, total pipe length from all affected new construction buildings is needed for statewide energy savings estimate. For DHW recirculation system pipe insulation improvement, the CASE study estimated pipe lengths for hot water supply, hot water return, and branch pipes, using the proposed ACM default design method for multi-family DHW systems. The proposed default design provides a compact recirculation loop design, thus, a conservative estimate of pipe lengths. The detailed calculation assumptions are listed in Figure 31.

	Low-rise Multi-family	High-rise Multi-family	Hotel / Motel
Dwelling Unit Area (sqft)	870	870	350
New Construction Unit	15373	13568	25995
Recirculation Supply Pipe Length (ft/unit)	16.2	8.1	5.1
Recirculation Return Pipe Length (ft/unit)	16.2	8.1	5.1
Branch Pipe Length (ft/unit)	6.7	8.0	8.0
Savings from Recirculation Supply Pipe Insulation (Therm/ft/Yr)	0.21 (2” diameter pipe)	0.14 (2.5” diameter pipe)	0.175 (average of low-rise & high-rise)
Savings from Recirculation Return Pipe Insulation (Therm/ft/Yr)	0.33 (0.75” diameter pipe)	0.33 (0.75” diameter pipe)	0.33 (average of low-rise & high-rise)
Savings from Branch Pipe Insulation (Therm/ft/Yr)	0.33 (0.75” diameter pipe)	0.33 (0.75” diameter pipe)	0.33 (average of low-rise & high-rise)
Statewide Energy Savings (Million Therms/Yr)	**0.168**	**0.088**	**0.136**

Figure 31 Statewide Energy Savings from Recirculation Loop Pipe Insulation

Measure	Building Type	Statewide Energy Savings (Million Therms/Year)
Air Duct Credit	Low-Rise MF	0.128
	High-Rise MF	0.032
Boiler Efficiency	High-Rise MF	0.003
Pipe Insulation	Low-Rise MF	0.168
	High-Rise MF	0.088
	Hotel/Motel	0.136
Total		**0.556**

Figure 32 CASE Study Statewide Energy Savings Estimate

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

This section provides detailed Title 24 language change recommendations. Figure 33provides a summary of the areas addressed by this CASE study and the corresponding Title 24 Standards or ACM sections.

Space Heating & DHW Topic	Code Language Sections
4.2.1 DHW Recirculation System Performance Algorithms	Residential ACM Appendix E
4.3.1 Air Distribution Duct The CASE study market study indicated that the air distribution ducts in multi-family buildings, if installed, were mostly located in conditioned spaces. This design practice is not fully reflected in the Title 24 residential and nonresidential ACMs, especially when the proposed heating system is a hydronic heating system. Standard system designs for low-rise multi-family buildings are defined in the Table R3-30 in the 2008 Title 24 Residential ACM. Hydronic heating systems and combined hydronic systems fall into the "All other gas heating" category and the corresponding standard design is "Split system air conditioner with gas furnace and air distribution ducts". Duct location and efficiency are treated in the same way as single family homes, according to the Table R3-31. This treatment provides an unnecessary energy budget associated with duct leakage losses, even for dwelling unit in low floors. Effectively, a compliance credit is provided to hydronic heating and combined hydronic heating systems. In the same way, unnecessary duct loss credits are provided to proposed designs belong to the "Any other electric heat including electric resistance, water source heat pump, etc." category.	Residential ACM Table R3-30
Error! Reference source not found. Error! Reference source not found.	Nonresidential ACM Table N2-14
Error! Reference source not found. Error! Reference source not found.	Title 24 Section 123 Table 123
Error! Reference source not found. Error! Reference source not found.	Title 24 Section 100

Figure 33 Recommended Language Reference Table

5.1 Title 24 Section 100 and Section 123

Section 100

Table 100-A APPLICATION OF STANDARDS (only the affect entries are shown)

Occupancies	Application	Mandatory	Prescriptive	Performance	Additions/Alterations
General Provisions					
Nonresidential, High-Rise Residential, And Hotels /Motels					
	Water Heating ~~(conditioned)~~	**113,123**	**145**		

Section 123

Table 123-A PIPE INSULATION THICKNESS

FLUID TEMPERATURE RANGE (°F)	CONDUCTIVITY RANGE (in Btu-inch per hour per square foot per °F)	INSULATION MEAN RATING TEMPERATURE (°F)	NOMINAL PIPE DIAMETER (in inches)					
			Runouts up to 2	1 and less	1.25 - 2	2.5-4	5 - 6	8 and larger
			INSULATION THICKNESS REQUIRED (in inches)					
Space heating systems **and processing** (steam, steam condensate and hot water)								
Above 350	0.32-0.34	250	1.5	2.5	2.5	3	3.5	3.5
251-350	0.29-0.31	200	1.5	2	2.5	2.5	3.5	3.5
201-250	0.27-0.30	150	1	1.5	1.5	2	2	3.5
141-200	0.25-0.29	125	0.5	1.5	1.5	1.5	1.5	1.5
105-140	0.24-0.28	100	0.5	1	1	1	1.5	1.5
Service water-heating systems (recirculating sections **and branch pipes connected to recirculation loops**, all piping in electric trace tape systems, and the first 8 feet of piping from the storage tank for nonrecirculating systems)								
Above 105	0.24-0.28	100	~~0.5~~**1**	~~1~~**1.5**	~~1~~**1.5**	~~1.5~~**2**	~~1.5~~**2**	~~1.5~~**2**
Space cooling systems (chilled water, refrigerant and brine)								
40-60	0.23-0.27	75	0.5	0.5	0.5	1	1	1
Below 40	0.23-0.27	75	1	1	1.5	1.5	1.5	1.5

5.2 Residential ACM Table R3-30 and R3-31

Table R3-30 – Summary of Standard Design HVAC System

Propose Design		Standard Design		
Heating	**Cooling**	**Heating**	**Cooling**	**Detailed Specifications**
Through-the-wall heat pump		Same equipment as proposed design with no air distribution ducts		Equipment efficiency determined by CEC Appliance Efficiency Regulations
Gas wall furnace with or without ducts and/or circulation fan	Any	Same equipment as proposed design with no air distribution ducts	Same equipment as proposed design with no air distribution ducts	
Any other electric heat including electric resistance, water source heat pump, etc.	Any	Split system heat pump with air distribution ducts**;** **For multi-family buildings, air distribution duct configurations are the same as those in the proposed design.**		SEER per Package D Verified refrigerant charge (prescriptive requirement) No credit for sizing No credit for cooling coil airflow No credit for reduced fan power
All other gas heating	Any	Split system air conditioner with gas furnace and air distribution ducts. **For multi-family buildings, air distribution duct configurations are the same as those in the proposed design.**		
Note: The standard design cooling system is also used for the proposed design if the proposed design has no air conditioning				

Table R3-31 – Summary of Standard Design Air Distribution System

This table is applicable only when the standard design system has air distribution ducts as determined in Table R3-30. **For multi-family buildings, air distribution duct configurations are the same as those in the proposed design.**

Configuration of the Proposed Design	Standards Design	
	Standard Design Duct Location	**Detailed Specifications**
Attic over the dwelling unit	Ducts and air handler located in the attic	Ducts sealed (prescriptive requirement) No credit for reduced duct area No credit for increased duct R-value or buried ducts No credit for low-leakage air handler
No attic but crawlspace or basement	Ducts and air handler located in the crawlspace or basement	
No attic, crawlspace or basement	Ducts and air handler located indoors	

5.3 Nonresidential ACM

Table N2-14 – System #1 and System #2 Descriptions

Ducts: For ducts installed in unconditioned buffer spaces or outdoors as specified in § 144(k), the duct system efficiency shall be as described in Section 2.5.3.18. **For All residential including hotel/motel guest room, the standard design and the proposed design shall use the same duct system efficiency.**

Table N2-15, N2-16, and N2-17

Heating System: Gas **hot water** *boiler*

5.4 Residential ACM Appendix E

The CASE study proposes to revise residential ACM Appendix E, Water Heating Calculation Method, to incorporate the new recirculation and branch heat loss calculation models, as well as standard and default DHW distribution network designs. This proposed change will be applicable to high-rise multi-family, motel and hotel buildings, which are covered by the nonresidential ACM, but follow the residential ACM Appendix E for central DHW systems performance calculation.

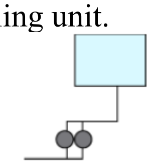
E1 Purpose and Scope

This ACM **section**~~*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.

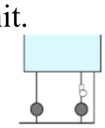
When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

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

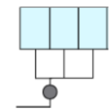
1. One distribution system with ~~*two*~~**one or multiple** water heaters serving a single dwelling unit.



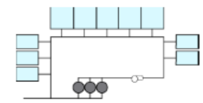
2. Two distribution systems, each with a single water heater serving a single dwelling unit.



3. One distribution system **without recirculation loop and** with one **or multiple** water heater**s** 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.



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

(No change)

E3 Hourly Adjusted Recovery Load

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

Equation RE-1 $HARL_k = HSEU_k \times DLM_k$ **$- HSEU_k \times SSF_k$** ~~$\times SSMk$~~ $+HRDL_k + \sum_l HJL$

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

SS**F**~~*M*~~$_k$ = ~~*Solar Savings Multiplier (unitless) See equation RE-7*~~**Solar savings fraction (unitless) for the kth 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-1**0**~~1~~.

…

(No change)

…

~~*Equation RE-7 SSMk = 1-SSFk*~~

~~*Where*~~

~~*SSMk = the solar savings multiplier (unitless) for the kth 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.*~~

…

(No change)

…

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,** ~~V~~**v**alues 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.**

…

(No change)

…

E4 Hourly Recirculation Distribution Loss for Central Water Heating Systems

(The recommended calculation method for this section has very large difference with the existing ACM method. Most of the existing language within this section is recommended to be deleted to be replaced with the following recommended language.)

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~~**L**M)**, 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 pip**es**~~*ing*~~ to individual ~~*residential*~~**dewlling** units. T**he hourly values of t**hese losses**, HRDL, shall be calculated according Equation RE-10. Compliance software shall provide input for specifying recirculation system designs and controls according to the following algorithms.** ~~*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/°F).

$T_{IN,n}$ = Input temperature of section n (°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 (°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 (°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 $T_{End,n} = T_{Amb,n} + (T_{Start,n} - T_{Amb,n}) \cdot e^{-\frac{UA_n}{Vol_n \cdot \rho \cdot C_p \cdot f_{UA}} \cdot (1 - SCH_{k,m})}$

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	
	$T_{IN,1}$ (^oF)	$SCH_{k,m}$	$T_{IN,1}$ (^oF)	$SCH_{k,m}$	$T_{IN,1}$ (^oF)	$SCH_{k,m}$	$T_{IN,1}$ (^oF)	$SCH_{k,m}$
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 $$HBUL = \left(\frac{GPH_k}{Nbranch_k}\right) \cdot \rho \cdot C_p \cdot \left(T_{IN,b} - T_{OUT,b}\right)$$

where

$T_{IN,b}$ = Average branch input temperature (°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 (°F). See equation RE-21

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

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 (°F) 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 $Nbranch_k = INT\left(\frac{Nunit}{N_{unit,b} \cdot NK} + 0.5\right)$

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

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

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.

<u>Table RE-6 Pipe Sizing Schedule</u>

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

(The rest of section E4 is recommended to be deleted.)

E6.9 Electricity Use for Circulation Pumping

(The single-family portion is not affected by this CASE study)

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

where

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

$PUMP_k$ = Pump brake horsepower (bhp).

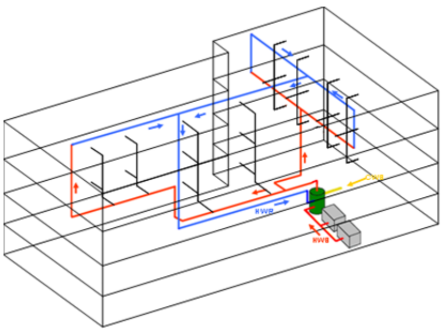
η_k = Pump motor efficiency.

$SCH_{k,m}$ = Operating schedule of the circulation pump**<u>, 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.</u>**. ~~*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.*~~

6. Appendices

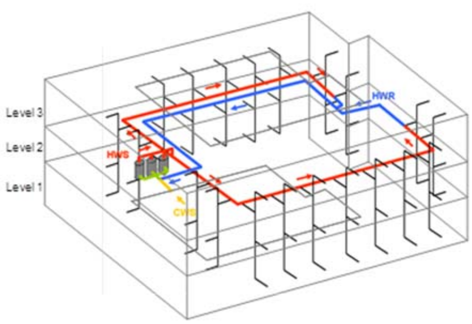
6.1 Appendix I - Recirculation Loop Model Validation Results

Building 1. Recirculation loop loss represent 34% Total hot water energy



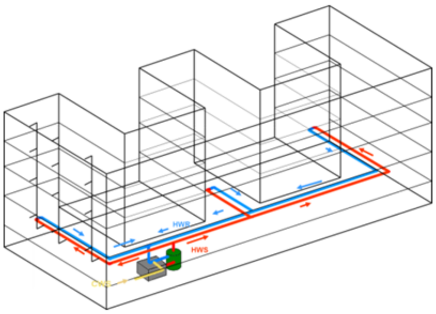
SFD	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	608,711	608,711	-	-	639,732	643,487	-	-	1,875,663	1,879,417	-	-
Temp Mod	600,697	582,695	1.3%	4.3%	633,433	616,266	1.0%	4.2%	1,958,764	1,941,597	-4.4%	-3.3%
Timer	507,048	461,656	17%	24%	600,803	562,822	6.1%	13%	1,732,428	1,694,446	7.6%	10%
Demand	215,483	191,328	65%	69%	411,903	453,556	36%	30%	1,423,628	1,465,281	24%	22%

Building 2. Recirculation loop loss represent 42% Total hot water energy



SAM	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	368,536	368,536	-	-	443,280	456,190	-	-	1,030,479	1,043,388	-	-
Temp Mod	362,987	355,698	1.5%	3.5%	442,840	435,949	0.1%	4.4%	1,030,039	1,023,148	0.0%	1.9%
Timer	265,214	279,559	28%	24%	421,494	419,521	5%	8%	1,008,693	1,006,720	2.1%	3.5%
Demand												

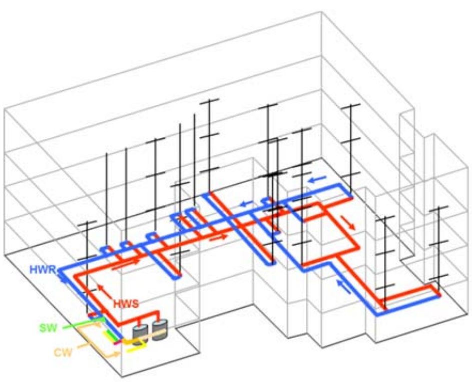
Building 3. Recirculation loop loss represent 7% Total hot water energy



Comparison to measured results

	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SFF	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	176,588	176,588	-	-	221,165	228,267	-	-	3,116,211	3,123,313	-	-
Temp Mod	157,692	159,541	11%	10%	204,820	204,057	7%	11%	2,564,910	2,564,146	18%	18%
Timer	151,829	147,709	14%	16%	220,452	228,777	0.3%	-0.2%	3,443,807	3,452,131	-11%	-11%
Demand	48,168	78,002	73%	56%	178,093	179,729	19%	21%	2,784,551	2,786,187	11%	11%

Building 4. Recirculation loop loss represent 14% Total hot water energy



Comparison to measured results

	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SFH	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	177,796	177,796	-	-	201,589	207,200	-	-	1,094,813	1,100,423	-	-
Temp Mod			-	-			-	-	-	-	-	-
Timer	143,549	145,345	19%	18%	187,240	194,233	7%	6%	942,592	949,586	14%	14%
Demand	90,349	82,244	49%	54%	180,478	173,723	10%	16%	742,710	735,955	32%	33%

6.2 Appendix II - Residential Construction Forecast Details

6.2.1 Summary

The Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from the California Department of Finance and California Construction Industry Research Board (CIRB) building permits. The Department of Finance uses census years as independent data and interpolates the intermediate years using CIRB permits.

CASE stakeholders expressed concern that the Residential forecast was inaccurate compared with other available data (in 2010 CEC forecast estimate is 97,610 new units for single family and the CIRB estimate is 25,526 new units). In response to this discrepancy, HMG revised the CEC construction forecast estimates. The CIRB data projects an upward trend in construction activity for 2010-2011 and again from 2011-2012. HMG used the improvement from 2011-2012 and extrapolated the trend out to 2014. The improvement from 2011-2012 is projected to be 37%. Instead of using the percent improvement year on year to generate the 2014 estimate, HMG used the conservative value of the total units projected to be built in 2011-2012 and added this total to each subsequent year. This is the more conservative estimate and is appropriate for the statewide savings estimates. Based on this trend, the new construction activity is on pace to regain all ground lost by the recession by 2021. The multi-family construction forecasts are consistent between CEC and CIRB and no changes were made to the multi-family data.

Residential New Construction Estimate (2014) in total dwelling units			
	Single Family	**Multi-family Low Rise**	**Multi-family High Rise**
CZ 1	378	94	-
CZ 2	1,175	684	140
CZ 3	1,224	863	1,408
CZ 4	2,688	616	1,583
CZ 5	522	269	158
CZ 6	1,188	1,252	1,593
CZ 7	2,158	1,912	1,029
CZ 8	1,966	1,629	2,249
CZ 9	2,269	1,986	2,633
CZ 10	8,848	2,645	1,029
CZ 11	3,228	820	81
CZ 12	9,777	2,165	1,701
CZ 13	6,917	1,755	239
CZ 14	1,639	726	-
CZ 15	1,925	748	-
CZ 16	1,500	583	-
Total	47,400	18,748	13,845

Figure 34. Residential construction forecast for 2014

6.2.2 Additional Details

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ). These 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and decay rate. Total construction is the sum of all existing dwelling units in a given category (Single family, Multi-family low rise and Multi-family high rise). Decay rate is the number of units that were assumed to be retrofitted, renovated or demolished. The difference in total construction between consecutive years (including each year's decay rate) approximates the new construction estimate for a given year.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has segmented all multi-family buildings into low rise and high rise space (where high rise is defined as buildings 4 stories and higher). This calculation is based on data collected by HMG through program implementation over the past 10 years. Though this sample is relatively small (711), it is the best available source of data to calculate the relative population of high rise and low rise units in a given FCZ.

Most years show close alignment between CIRB and CEC total construction estimates, however the CEC demand forecast models are a long-term projection of utility demand. The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022, and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure), however to estimate next year's construction, CIRB is a more reliable data set.

6.2.3 Citation

"Res Construction Forecast by BCZ v4"; Developed by Heschong Mahone Group with data sourced September, 2010 from Sharp, Gary at the California Energy Commission (CEC)