CODE CHANGE PROPOSAL FOR:

Multifamily Water Heating

MAY 7TH, 2002

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Overview

Description

There are two changes to the standards included in this Proposal. Both are specific to water heating in multifamily buildings.

First, we propose to establish a custom water heating budget methodology (base case equation and assumptions set) to represent central water heating systems for multifamily buildings. Multifamily buildings with central systems would no longer be compared to multifamily buildings with individual water heaters.

The second change involves amendments primarily to the Alternative Compliance Method (ACM) procedures. We propose new modeling assumptions that better represent hot water distribution system losses and the impact of controls, insulation and other specific improvements to the systems.

Benefits

Over a quarter of all the energy used for water heating in California is used in multifamily buildings.[1] For multifamily buildings, standard water heating energy budget calculations assume NAECA minimum individual water heaters, consistent with how the budget is established for single family buildings. This consistently overestimates water heating energy compared to central water heating systems. This creates a substantial *apparent* energy savings when central DHW systems are used, which is typically traded off with reductions in the efficiency of the envelope and HVAC systems. Closing this loophole will result in buildings that include the standard envelope and HVAC measures that have been shown to be cost-effective, and are, therefore, more comfortable and affordable to operate.

There are two primary benefits of more accurately accounting for hot water distribution losses and measures that can mitigate those losses. First, if the distribution losses are properly calculated, less *apparent* energy savings will be available for trading off. Depending upon the building design and piping layout, pipe losses can nearly double the energy use of the water heating system. Under current code and with the current ACM assumptions, the same building with its central DHW system appears to use nearly 25% less water heating energy than the budget. Secondly, if the distribution losses are correctly included, then controls on re-circulating hot water loops and other upgrades that can produce real energy savings will emerge as logical design choices. Some of these measures will not only save energy but reduce peak energy use. Aligning the computer models with reality will help building designers and owners make economic decisions with costs and savings that they can count on in their monthly operating expenses.

Time Dependent Valuation (TDV) affect on benefits attributed to the measure.

Almost all of the energy used for water heating in new MF construction in California is from natural gas, therefore TDV will have little to no effect on the benefits of this measure. There are, however, two relevant issues. First, for this analysis we assumed no seasonal variation in hot water usage. There is some evidence that there might be a significant seasonal component to real water heating draw schedules, but we do not yet have enough California field data to support making a change from the CEC's current methodology. We are proposing further research (see Appendix E) to gather empirical data on actual usage patterns in California. If that research supports creation of a draw schedule with seasonal variations for future rounds of Standards, then a TDV approach that values gas energy higher in the winter than the summer might affect the benefits of the measures in the current proposal.

Secondly, Charles Eley Associates is developing a new water heating calculation methodology that would include an hourly (8760 hours) custom budget calculation for water heating similar to what is now done for space conditioning. If that

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[1] 1999 Residential Energy Survey. Pacific Gas and Electric Company.

proposal is adopted by the Commission then a TDV evaluation of water heating may provide a different set of relative benefits for the water heating distribution system upgrades for which we are proposing credit. Again, the effect would probably be fairly small compared to other end uses and other measures.

Environmental Impact

The proposed changes will have no significant negative environmental impacts. Water consumption may be slightly increased (compared to re-circulation systems without controls) if re-circulation controls were to become more prevalent due to this change, but our survey of new building plans indicates that re-circulating distribution systems are the norm for MF buildings with central systems. Closing the loophole will save significant energy and reduce emissions. There are no other significant environmental impacts.

Type of Change

The water heating budgets we are recommending for multifamily buildings are based on a similar set of assumptions of use per square foot, types of usage and schedules as those that were used for creating the current single family residential water heating budgets. There may be good reasons for multifamily water heating budgets to be smaller than for single family homes, but we lacked sufficient empirical data to justify revising the assumptions for this round of Standards.

Title 24, Part 6, Section 151(b)1. currently has only one Annual Water Heating Budget Equation, which assumes a 50 gallon water heater that (a) just meets the Appliance Standards (Title 20). This proposal would add a second equation to be used for multifamily buildings with central water heating systems. It also proposes a set of prescriptive compliance requirements for central water heater systems serving multifamily buildings. Also, this proposal will result in changes to the modeling assumptions and modeling capabilities of the ACMs.

The second change proposed here (providing multipliers for measures that increase or decrease distribution losses) will also not create new requirements for systems or equipment that were not previously regulated, but will add the ability to model types of controls used in multifamily buildings that are currently not modeled. These recirculation control types can currently be modeled in single family buildings.

Both of these changes will require changes to the Standards, the compliance manuals and the ACM manuals. Since low-rise residential multi-family buildings will continue to be modeled with residential ACMs and high-rise multi-family residential buildings will continue to be modeled using nonresidential ACMs, both ACM manuals and both compliance manuals will require changes. The ACM manuals will provide guidance on new modeling procedures for central water heating and recirculation controls in multifamily buildings. The compliance manuals will provide new forms and instructions for central water heating and control credits.

The effects of this proposal on the relevant sections of the Standards are:

- Section 151(f)8 references the water heating budget calculation or allows for 50 gallon water heaters with energy factors (EF) of 0.58 or better. This proposal would change this to distinguish between multifamily residential buildings that have individual water heaters (in which case there is no change), and residential buildings that have central water heating systems. For multifamily buildings with central DHW systems, the new water heating prescriptive requirement would be:

  a) Multifamily buildings with central water heating would have to meet a new central water heating budget – the equation would be similar to and directly after Equation 1-N in Section 151 (see next bullet below), or

b) Have a gas boiler that meets the minimum efficiency listed in Table 1-C11, Section 113, and a re-circulation pump with a control capable of automatically turning off the circulating pump when hot water is not required.

- Section 151(b)1. provides an equation (1-N) for calculating the allowable Annual Water Heating Budget (AWB). The equation is based on an assumption of a single minimally efficient 50 gallon or less water heater per residence. As a comparison of how an annual water heating budget for central water heating would be implemented if there were no other changes to the water heating requirements, we provide a new equation for multifamily projects with a central DHW system. However, there is a parallel proposal from Eley Associates, to change the water heating budget calculation method to an hourly methodology. These are two major changes to the way water heating energy is now treated. The two proposals can be combined into one and the details of implementation worked out after the merits of each major change are discussed separately in a public workshop.

The Prescriptive Packages section (Chapter 3) of the Residential Manual will have to be edited to reflect these changes. Specifically, the prescriptive requirements for central water heating in MF buildings will be described and a new table of "Complying Central Water Heating Systems for MF Buildings" will be developed.

The Computer Method section (Chapter 5) of the Residential Manual will need a relatively minor revision. The primary changes will be to Chapter 6, Water Heating Calculations. After the *Hourly Water Heating Calculations* proposal from Eley Associates and this proposal are adopted by the Commission, Eley Associates and HMG will develop language that includes an hourly analysis methodology for central systems in MF buildings including the assumptions and the minimum installation requirements.

Technology Measures

Closing the central water heating loophole will result in several cost effective measures in the prescriptive package becoming routine for multi-family compliance. These measures have already been shown to be cost effective and readily available. The only technologies that this measure specifically encourages more than the existing standards are controls for re-circulation systems in multifamily buildings and pipe insulation with higher R-values. The following discussion is specific to these measures.

Measure Availability and Cost

All the controls considered in this analysis are currently allowed in the modeling of single family homes and are currently being used by some multifamily builders. Although the pipe insulation credit also already exists, higher R-value insulation coverings are not commonly used for domestic hot water piping, but are used for commercial and industrial applications. The incremental costs of adding an additional ½ inch of pipe insulation are in the range of ~$1/ft. to ~$2/ft. The Eley/DEG report on single family water heating distribution losses used a pipe insulation cost of $1.08/lf ($0.50 for materials, $0.33 for labor, and a 30% contractor markup). The costs they used were for adding insulation where none would otherwise have been whereas the costs in this analysis are incremental costs for increasing the thickness of insulation already required for re-circulating distribution systems.

For analysis of the impact of insulation improvements, the baseline condition was the minimum insulation already required as a mandatory measure by Section 150(j)2. of the Standards. For the re-circulating loops of distribution systems, that requirement is R-4 insulation for piping up to 2", and R-6 for pipes larger than 2".

Controls (temperature, time and time/temperature) are made by Honeywell, Pro-Temp, Grundfos, Barksdale, Tekmar and others. They generally cost in the range of $30 to $150. An extremely sophisticated controller that can "learn" occupant usage patterns and modulate water temperature and pump operation will cost significantly more. It was not modeled in this proposal because there are too few manufacturers, and to verify proper programming and calibration may be beyond what can reasonably be expected of the inspection community. This technology might soon be ripe for a compliance option analysis.

Useful Life, Persistence and Maintenance

This proposal has two parts: a new central water heating budget for MF projects with central water heating, and revised credits for "measures" that affect central water heating distribution systems. For the first "measure" in this proposal, a new budget for central water heating systems, useful life, maintenance and persistence are not germane.

The second part of the proposal encourages distribution loss control strategies. These measures are either proposed as compliance options or are already the de facto (market) base case. As such, the proposal doesn't require anything that increases issues of useful life, persistence and maintenance.

Performance Verification

Performance verification is not required for any of the measures proposed. The only verification required is that that installation was done according to design. This installation performance would require the same level of expertise and diligence currently required by other water heating measures.

Cost Effectiveness

The simplest approach to addressing the cost-effectiveness of our proposal to have a separate budget for central water heating systems in multifamily buildings is to recognize that this proposal adds no requirements that have not already been shown to be cost effective or which are not already being installed. This proposal would require that central systems have the pipe insulation that is already required by Sections 123 and 150(j), and a control on the re-circulation system, which is already required by section 113(c) for high-rise residential and strongly encouraged by the modeling assumptions in the Residential ACM Manual.[2] Compliance for multifamily central water heating systems is not currently allowed prescriptively, but must instead be modeled using an ACM. This new central water heating budget will therefore not add any new requirements to the packages, but simply will close a loophole that currently permits a significant trade off of prescriptive envelope requirements like ceiling insulation and fenestration performance. Our proposal better aligns the performance method with the intent of the prescriptive requirements, and as such, needs no further cost-effective analysis. It is important to note that these tradeoffs are not due to installation of some energy efficiency upgrade, at an incremental first cost; but rather are due to reliance on a water heating budget developed for single family residences, assuming an individual 50 gallon water heater. Central water heating is often installed purely because it offers a lower first cost. Therefore, any measures that would be cost effective given individual water heaters in each unit of a multifamily building, will be cost effective with a water heating system that both costs less to install and uses less energy on an annual basis.

The other portion of this proposal is essentially criteria, assumptions and an analysis methodology for a compliance option that will allow designers to model and evaluate various efficiency measures for central water heating distribution systems (e.g., controls, pipe location). As compliance options, no cost effectiveness analysis is required. Figure 1 provides a general range of savings potential from the options, along with an estimate of their incremental costs.[3]

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[2] "Alternative Calculation Method (ACM) Approval Manual for the 2001 Energy Efficiency Standards for Residential Buildings – April 5, 2001." Section 4.21.4, Table 4-8 indicates that the calculated energy use of a central re-circ system must be multiplied by 1.52 if uncontrolled, but by 1.05 with a temperature control.

[3] Currently, the estimates of savings from temperature and time/temperature controls is based on earlier research by others. We will refine our analysis of the impact of these two control strategies after the May 30, 2002 workshop.

	Savings Potential	Incremental Cost
Pipe Location	5% - 11%	$ -
Pipe Insulation	5% - 8%	$1-$3/ft.
Temperature Control		
Temp Only +	15%	*$30* ***
Time/Temp +	15% - 30%	$ 150.00
Time Control		
Night Only +	10% - 34%	*$50* ***
Night & Peak*	6% - 8%	$ - *
Peak Only*	<2% - 6%>	$ - *
Separate Laundry Center	<1%> - 4%	**

+ Compared to no control.
* Compared to "Night Only."

** These costs are too dependent upon building configuration to make an estimated average increment/decrement meaningful.
*** A time or temp control is standard practice, so these costs are assumed to occur and therefore not incremental.

Figure 1: Energy Savings and Cost of Improvements

Analysis Tools

The tools that are used for demonstrating compliance with the standards for water heating (e.g., MICROPAS or EnergyPro) under the current water heating calculation procedures would have to incorporate changes to allow for the new modeling assumptions of central water heating systems in MF buildings, and for establishing a standard budget for those systems. Work with Eley Associates to develop an hourly analysis approach for water heating similar to that used for space conditioning will include hourly recovery efficiency and distribution loss load factors for use by the new programs. Either way, this proposal will require changes to incorporate a model for a central water heating system and algorithms for modeling distribution system parameters not currently modeled – but will not require any new program.

Relationship to Other Measures

Table 1 shows a comparison between the prescriptive requirements and what is allowed just by taking credit for the central water heating loophole. For an example, Table 1 shows the prescriptive (Package D) requirements along with the type of trade-offs that would occur due to the *apparent* energy savings from using a central water heating system in a multifamily building. This example assumes no energy savings from any other loophole (e.g., fenestration area assumptions based on single family buildings). Although it is specific to Climate Zone 13, it is indicative of the extent of tradeoffs in all climate zones.

	Size (sq.ft.)	700	900	1100
	Prescriptive	Trade-off Results		
Insulation				
Ceiling	R-38	R-19	R-19	R-30
Walls	R-19	R-13	R-13	R-13
Floor	R-19	R-13	R-13	R-19
Radiant Barrier				
Attic	Required	NONE	NONE	NONE
Glazing				
U-factor	0.65	0.65	0.65	0.65
SHGC	0.4	0.4	0.4	0.4
Heating				
Efficiency	Appliance Stds Minimum	Minimum	Minimum	Minimum
Cooling				
Efficiency	Appliance Stds Minimum	Minimum	Minimum	Minimum
TXV	Required	NONE	NONE	NONE
Ducts				
Sealed	Required	NOT	NOT	NOT
DHW				
Budget	[(16370/CFA) + 4.85] (in kBtu/sf-yr)	28.2	23.0	19.7

Table 1: Prescriptive Requirements Traded-off due to Water Heating Loophole

Methodology

We provide two levels of explanation of the analysis methodology. The first below is just a brief outline to describe the general steps. Following that, is a more detailed explanation. Appendix A to C provides detailed analysis results.

Methodology Outline

The methodology we used was as follows:

1. Develop hourly hot water demand (gallons) for three prototypical apartment buildings.
   a) This is one set of 24 hour loads with no differences between type of occupants, seasons of the year, or day of the week.
   b) It is based on the same usage/S.F assumption as the single family analysis.
2. Develop models of the water heating and hot water distribution systems for the three buildings.
   a) These models included actual boilers, storage tanks, piping layouts and pumps from the original plans.
   b) This included calculating the UA for piping, differentiated by size, location and insulation characteristics.
3. Run base case and parametric analysis with DOE 2.2 on each of the models for the purpose of determining their relative effects on the distribution losses and total water heating energy. The parametrics included:
   a) Modified boilers and other details to the minimums required (e.g., 80% RE).
   b) Changes in piping location.

c) Changes in pipe insulation.
d) Adding a time control to the re-circulation loop.[4]
e) Three different time schedules.
f) A separate laundry center, with and without its own hot water source.

4. Develop the algorithms for a “standard” central water heating budget and for compliance modeling of variations in central water heating distributions systems.

Description of Methodology

We first collected data on new multifamily buildings in California. We restricted ourselves to those buildings for which we had or could get plan sets. We compared the relevant data on 28 new or soon-to-be-constructed MF buildings. We selected one each from the following categories as broadly representative of the body of multifamily new construction in the state:

- High-rise
- Low-rise
- Campus (multiple buildings with a shared DHW system)

Figure 2 below provides a description of the buildings in our sample. The three buildings highlighted in Figure 2 are the three we chose as our prototypes for modeling[5]. It should be noted that the water heater type for the campus building was an extremely complex system that included a ground source heat pump for filling a storage tank of over 4000 gallon capacity. It also included two gas boilers. The make-up “cold” water runs through a heat exchange loop in the large storage tank. To simplify our analysis and to make it more representative of the larger population, we modeled this building with a boiler and small storage tank. That is why there is no value for it in the efficiency column (note the “***”).

One of the key findings from this stage of the project was that when a central water heating system is designed/installed in a multifamily building, it always has a re-circulation pump. Another interesting observation is that the choice of central or individual water heaters does not seem to be dependent upon whether the multifamily building is for seniors, affordable housing or market rate. Market and high-end apartments also have central systems. However the townhomes (for-sale units) all had individual water heaters.

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[4] Two other control cases, temperature and time/temperature, will be modeled in June 2002.

[5] The projects were known by the names on the designers’ plans, which are abbreviated “CT,” “CBC,” and “LR.” These buildings are #2. #11, and #13, respectively.

							Water Heating					
No.	Description	CZ	# of Flrs	Conditioned Floor Area	# of Apts.	Type	Volume/ Type	Type	Effi- ciency	Notes	Hy- dronic ?	Recirc. Loop?
1	3 Story Senior	9	3	126,570	174	Senior	40 gal	gas	0.58 EF		Yes	No
2	Small Two Story Senior	10	2	32,027	40	Senior	Central	gas	80% RE	189g strg	No	Yes
3	Large 3 Story	9	3	83,764	114	Affdbl	Central	gas	82% RE		No	Yes
4	Medium Glazed 3 Story	10	3	32,610	52	Mkt	Central	gas	80% RE	274 gal. Storage	No	Yes
5	Medium 3 Story	10	3	95,004	108	Senior	Central	gas	82% RE	1260 gal. Storage	No	Yes
6	Small, 2 Story, Senior	9	2	16,628	11	Senior	30 gal	gas	0.61 EF		No	No
7	Medium, 1 Story, Senior	10	1	41,550	75	Senior	32 gal	gas	0.58 EF		No	No
8	Highly Glazed 2 Story	6	2	11,082	20	Affdbl	48 gal	gas	0.60 EF		Yes	No
9	Medium 4 Story	8	4	101,194	104	Mkt	40-50 gal	gas	0.62 EF		Yes	No
10	2 Story Large Campus	9	2	220,194	201	mkt/affd	50 gal	gas	0.53 EF		no	no
11	6 Story Luxury Apts.	7	6	91,350	86	mkt/Lux	Inst x 2	gas	80% RE	2 x 174 gal. Storage	no	yes
12	Large, 2 Story Apts	14	2	80,000	81	mkt/Fmly	50 gal	gas	0.60 EF		no	no
13	Campus w/ Cnt DHW	12	2	12,783	92	student	Central	ht pump	***		yes	yes
14	Low-rise, senior	7	2	26,457	45	senior	Central	gas	80% RE	2x115 gal. Storage	yes	yes
15	12 Story, High-rise apts.	7	12	334,885	326	mkt	Central	gas	82% RE		yes	yes
16	Medium, Low-rise, market	7	2	76,000	76	mkt	40 gal	gas	0.56 EF		no	n.a.
17	Medium, Low-rise, market	7	3	102,280	112	mkt	Central	gas	76% RE		no	yes
18	Small, Low-rise, market	7	2	29,000	21	mkt	Central	gas	82% RE		no	yes
19	Large, Low-rise, market	7	3	193,800	180	mkt	50 gal	gas	0.60 EF		yes	n.a.
20	Lg., Low/high-rise, market	7	2	106,900	127	mkt	Central	gas	81% RE	150 gal. Storage	no	yes
21	Small Townhs. Complex	7	2	6,130	4	twnhs	40 gal	gas	0.60 EF		yes	n.a.
22	Medium Townhs. Complex	10	2	82,000	88	twnhs	50 gal	gas	0.58 EF		no	n.a.
23	Large, Low-rise, market	7	2	164,220	183	mkt	2x75 gal	gas	0.52 EF	2x75 gal WHs in each of 19 bldgs.	no	yes
24	Medim, Low-rise, senior	10	1	67,139	84	senior	Central	gas	80% RE	unable to determine re-circ loop	no	?(prob)
25	Large, High-rise, market	7	4	154,646	281	mkt	Central	gas	84% RE	3 boilers, one just for heating	yes	yes
26	Medium Low-rise, market	7	2	99,000	96	mkt	50 gal	gas	0.53 EF		no	n.a.
27	Small Townhs. Complex	10	2	8,400	*12*	twnhs	40 gal	gas	0.63 EF		no	n.a.
28	Small Townhs. Complex	7	2	14,985	9	twnhs	ind. Inst.	gas	83% RE	individual instanataneous WHs	yes	n.a.

Figure 2: Building Descriptions

From the drawing sets, we selected the following buildings for our detailed analysis:

1. a two story single building senior project in Norco, near Riverside, completed in 2001 (No. 2).
2. a six story single building "market" project in San Diego, completed in 2001 (No. 11).
3. a 27 building project with two- and three- story student apartments in Davis, completed in 2000 (No. 13).

Central water heating (CWH) design details including key re-circulation loop specifications were available for all three of these projects. DEG developed individual water heating (IWH) designs and the individual apartment and building draws for each project.

We had originally intended to also model combined hydronic heating with central DHW systems. After looking at the building descriptions, we decided against doing so. There were a couple system designs that we could not positively determine the composition of, but for all those that we could, none (except the campus complex) had hydronic heating using the same boiler(s) as the domestic hot water. Some buildings employed combined hydronic systems with individual water heaters. Others had boilers, but the hydronic system had its own boiler. One set of buildings (not in our final three) used two water heaters for each four-plex, and it was unclear whether the two water heaters had one distribution system serving both DHW and hydronic heating, or if they were dedicated.

While the overall goal of the multifamily water heating work was to establish independent compliance paths for projects with CWH systems and projects with IWH by apartment, we decided that it would be valuable to analyze several typical projects with both system types: total water heating energy for the same buildings with individual water heaters, as opposed to central water heating. This analysis will allow us to identify the potential energy savings of closing this loophole in the standards. We selected projects from available CWH drawing sets, since we could more accurately develop IWH designs for projects with central systems than vice-versa.

Once we chose the three buildings to be our prototypes, Davis Energy Group (DEG) estimated the hot water draws for individual apartments over a 24-hour period. To do this DEG used HWSim and the basic methodology they created for the

CEC in 1990-92. After much discussion between the "hot water team" and CEC staff, we chose to continue applying the same floor-area based hot water end-use quantities (draws) and profiles (draw schedules) to both single-family and multifamily units. However, we also decided to modify DWH distribution losses with floor area and number of stories to match the new single-family distribution loss recommendations (see companion document entitled, "Single Family Water Heating Distribution Loss Evaluation Report"). While a case can be made for three other modifications to the draws and draw schedules[6], we made only one exception to the "size and stories only" basis for hot water end-use quantities. That change was to develop load patterns both with and without central laundry facilities.

The hot water loads provided by DEG account for pipe losses for the piping within the individual apartments (but NOT any piping before the apartment) and assume a 100% efficient water heater at the piping entrance to each individual apartment. DEG then totaled up the demand on the water heating system for all apartments within a building (or campus complex). These totals represent the hot water draws that are applied to the re-circulation loops in those buildings.

Next, we built DOE2 models for each of the three buildings for analysis with DOE2.2. DOE2.1 is the engine for the compliance programs, but DOE2.1 does not have the capability of analyzing distribution piping losses. The use of DOE2.2 in this analysis does not preclude the continued use of DOE2.1 in the compliance programs. We will provide adjustment factors (multipliers) for the compliance programs.

Features and assumptions for the prototypes and for modeling are as shown below:

- minimum efficiency boiler sized for the peak load (demand)
- piping length shown in the building plans
- piping installed to code and standard engineering practices (e.g., pipe sizing and insulation)
- all systems have a re-circulation loop
- 5% of the re-circulation piping is outdoors
- pumps and flows are designed to meet a maximum draw equivalent to ~3 times the peak hour draw
- pumps, piping and flows are designed to maintain a temperature drop of no more than 15°F in the loop
- time control that shuts off the re-circulation pumps for 8 hours overnight

The specific parametric variations we examined include:

- insulation increased by ½" on all re-circulation piping
- variations in the location of the piping
  1. 0%, 5%, 33% 80% and 100% outside the envelope
  2. piping outside the envelope in ambient air vs. underground
- three schedules on the timer control
  1. night shut off (hours 24 – 6)
  2. peak shut off (hours 8-10 and 16-18)
  3. dual shut off (night + peak schedules)
- temperature control (aquastat)[7]
- time/temperature control (temperature control above with the night shutoff above)[8]
- separate laundry facilities (with and without a separate boiler)

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[6] Some available data show reduced hot water demand in senior occupied buildings. Other data suggest increased hot water use in CWH systems when users are not billed based on their own use quantities. Still other data provide evidence that draws and draw schedules should vary by season of the year. See Appendix Y for discussion of these impacts. The "hot water team" recognizes that each of these factors may have an impact on energy use. However, without better, targeted data, the team and CEC agreed that we should maintain the assumptions used in the 1990-92 analysis. We are proposing additional research to address these issues for the future so that we may further refine the water heating analyses within the next round of standards revisions. Please see Appendix E for a description of our research recommendations.

[7] The temp control and time/temp control cases are not yet complete due to the need for additional programming in DOE 2.2.

[8] See previous footnote.

- re-circulation system without controls (just as a boundary case)
- all cases were run in Climate Zones 3, 7, 9 and 12

Some cases that we initially considered but did not complete the analysis on are listed below along with the reasons for rejecting the cases.

- Demand control – although demand control is an effective strategy for energy savings in single family homes, we determined that the simplest form is inappropriate for multifamily buildings and analysis of the more complex form is beyond the scope of this study. The simpler form relies on the occupant pressing a button to initiate the pumping. This is not feasible for many multifamily buildings due to the complexity of the wiring that would be needed to place a demand button at key locations in each apartment.
  The more complex demand control is a system that senses demand by a change in pressure at certain points in a re-circulation loop. It responds to the change by cycling the pump on and then "remembers" the pattern of usage. After a period of time, it establishes an efficient schedule for re-circulation, essentially becoming a time control.
- Temperature modulating control – this type of control does not switch off the re-circulation pump but modulates the boiler output temperature based on need as determined by re-circulation return temperature. Although this is a fairly common strategy on the East Coast, it is not used much in California. Additionally, the analysis would add a very high level of complexity beyond the current methodology –from necessitating new draw schedules to a new iterative DOE 2 algorithm.. We determined that if a manufacturer saw an economic advantage to pursuing this analysis that this might make an appropriate compliance option, but that the rewards did not justify the effort within this project.
- Hydronic heating – we could not find any cases among the building designs reviewed that had a combined hydronic/DHW system with central water heating. The buildings either did not have hydronic heating, had a separate dedicated boiler for the hydronic system, or had individual water heaters with combined hydronic applications.

Using regression analysis, we then determined the relative impact on distribution losses, total water heating energy and total building energy from each of the variables.

Results

Analysis of the water heating energy of buildings with central DHW systems using current compliance programs, indicates that these systems are 20%-60% more efficient than individual water heaters. Our analysis for this proposal supports the position that central water heating is more efficient. However, by performing a better model of the distribution system losses, we show that the energy advantage of central systems over individual water heaters is not as great as would appear from the current compliance programs.

Table 2 shows that the current budget for these buildings underestimates the energy use (when distribution losses are accounted for) for MF buildings with larger apartments and overestimates it for buildings with smaller apartments. The new central water heating budget more accurately represents central water heating energy use for MF buildings. The apparent penalty that the "LR " building would face is related to unusually large amount of distribution piping it has for the number of square feet of living space

Table 2:Comparison of DHW Budgets for Three Prototypical Buildings in Climate Zone 7

MF Project (from Figure 3)	Avg. Apt. Size CFA (sf)	Total Building CFA (sf)	DHW kBtu/yr*sf		
			2001 ACM (current budget)	Simulation w/ Pipe Losses	New Central DHW Budget$_{CZ-7}$
#2 (CT)	593	32027	32.5	28.86	28.85
#11 (CBC)	1038	91350	20.6	22.09	21.91
#13 (LR)	1335	122783	17.1	23.78	19.86

The results of our analysis also show that the location of the distribution system piping is one of the largest factors in improving overall DHW efficiency with a central system. Until pipe insulation with dramatically better R-values is readily available and at lower costs, the maximum insulation upgrade that should receive credit is 1½" for small pipe sizes and 2" for larger sizes (versus the mandatory minimums of 1" and 1½" respectively). This level of insulation does not provide as much savings as simply moving most of the piping within the envelope. Additionally, the energy savings from the insulation upgrade is approximately the same regardless of the location of the piping. In other words, the percentage benefit of adding the additional insulation is not significantly different for piping inside the envelope (e.g., in the plenum) than for piping outside the envelop.

Using the actual pipe lengths for the prototype buildings but modifying the system descriptions to the other base case assumptions (e.g., 5% of the piping outdoors, night time pump shutoff, etc.), we analyzed the total water heating energy and the pipe losses for the three prototypes. The distribution losses range from just under 15% to over 25% of the total DHW load.

Table 3: Distribution Losses as a Percentage of Total DHW Energy

Project No.	CZ03	CZ07	CZ09	CZ12
#2	16.9%	15.4%	15.0%	15.5%
#11	15.0%	14.1%	13.5%	13.4%
#13	25.0%	23.6%	22.4%	22.8%

One of the factors which makes a difference in the amount of distribution losses, and therefore the total water heating energy, is the relationship of re-circulation pipe length to CFA (pl/CFA). This ratio, given in lineal feet per square foot (lf/sf), ranges from 0.0120 to 0.0191 in the buildings we modeled, with the median being 0.016. The graphs (Figure 3, Figure 23, Figure 24, and Figure 25) we present comparing the effect of other measures indicate the pl/CFA ratio at the top to provide additional context for the comparisons. We did not manipulate the building pipe layout to affect this ratio. The piping was designed (by the original engineers) to meet the building loads given the other constraints of the building design. To artificially revise a detail so intricately bound to the rest of the building design would have required creating a virtually brand new case. Therefore each building maintains its original lp/CFA ratio throughout the analysis.

Our analysis on the temperature control and time/temperature control credits is still pending at this time. Research done by Lobenstein, et al, in 1992 showed that a "demand" control - similar to the time/temp control we are modeling – can save 15%-17% over a simple temperature control (Aquastat), and 2%-9% over a simple time control.

We ran all the parametrics in four climate zones (3, 7, 9 and 12). Although the recovery load is relatively unaffected by climate zone differences, the distribution losses are. The distribution losses in the cases where much of the distribution system is outside the building envelope vary more significantly. Since there is some sensitivity to climate zone with all distribution system measures, and significant sensitivity with some measures, we propose to create separate multipliers (for the proposed case) for each climate zone. At the time of this stage of the analysis, it was uncertain whether it would be appropriate to develop multipliers for an annual model or an hourly model, so this work is pending until after the May 30, 2002 workshop. (For an indication of the climate zone dependency of the sum of important measures for central water heating, see the CZ dependent multipliers for the annual water heating budget in Table 4.)

Recommendations

Annual Water Heating Budget For Central DHW Systems

If we assume that the Eley proposal for a change in the water heating budget calculation to a set of hourly algorithms is accepted, then the value of the following discussion is a demonstration of comparability with the existing water heating budget method. All of the factors that are condensed into (or represented by assumed values in the derivation of) the following equation, can be applied to an hourly model. Since we do not know at this time the form that the hourly model may take, we offer only general advice on how to implement multipliers for the factors we found to be significant. That discussion follows this one.

The equation for the annual water heating budget (standard budget) equation for CHW systems would take roughly the same form as in the current version of the Residential ACM. The only difference is that the constant "C" is different for each climate zone. Following is the equation in two forms:

AWB(kBtu/(yr*sf)) =

$$\sum_{x=A}^{i} n_x \{\, \mathrm{nA}[(\mathrm{Ccz}/\mathrm{CFAA}) + \mathrm{YCZ}] + \mathrm{nB}[(\mathrm{Ccz}/\mathrm{CFAB}) + \mathrm{YCZ}] + \ldots \mathrm{ni}[(\mathrm{Ccz}/\mathrm{CFAi}) + \mathrm{YCZ}\} / (\mathrm{nA} + \mathrm{nB} + \ldots \mathrm{ni})$$

Where, C_{CZ} is a different number (slope) dependent upon climate zone,
n_i is the number of units of type (size) "*i*",
CFA_i is the conditioned floor area of apartments of type "*i*",
Y_{CZ} is the *Y*-intercept – dependent upon climate zone

Specifically, the equation for CZ-7 is:
AWB (kBtu/(yr*sf)) =Sum{ $n_A[(9478/CFA_A) + 12.58] + n_B[(9478/CFA_B) + 12.58] + \ldots n_i[(9478/CFA_i) + 12.58\}/(n_{A+}\ n_{B+ \ldots}\ n_i)$

In its simplified form, the equation for Climate Zone 7 looks like this:

$$AWB_{kBtu/yr\cdot sf} = \frac{\sum_{x=A}^{i} n_x \left[\left(9478/CFA_x\right) + 12.58\right]}{\sum_{x=A}^{i} n_x}$$

Where;

CFA_x is the conditioned floor area of apartment type *x, and*
n_x is the number of apartments of type *x* in the building

Table 4 shows the value of C_{cz} and Y for Climate Zones 3, 7, 9, and 12.

Table 4: Constants for Annual Water Heating Budget Equation

	C	Y
CZ 03	9603	12.66
CA 07	9478	12.58
CA 09	9971	13.00
CZ 12	10,201	13.17

The idea of the water heating budget varying by climate zone is a change from current practices, but is appropriate given the impacts of measures. For example, the impact of placing more of the distribution piping outdoors or underground (such as would happen in a campus situation with central DHW) varies significantly by climate zone. Figure 3 shows the water heating energy for the smaller of our three prototypical buildings – the one for which the amount of distribution piping per square foot of building was closest to the median. The *X*-axis is the percentage of the piping that is outside the building envelope. The graph shows that not only do the energy losses from the distribution system increase by climate zone, but the rate at which pipe losses increase as you move more piping outside are also different by climate zone. We capture this and the effect of climate zone differences in both the "C" and "Y" values.

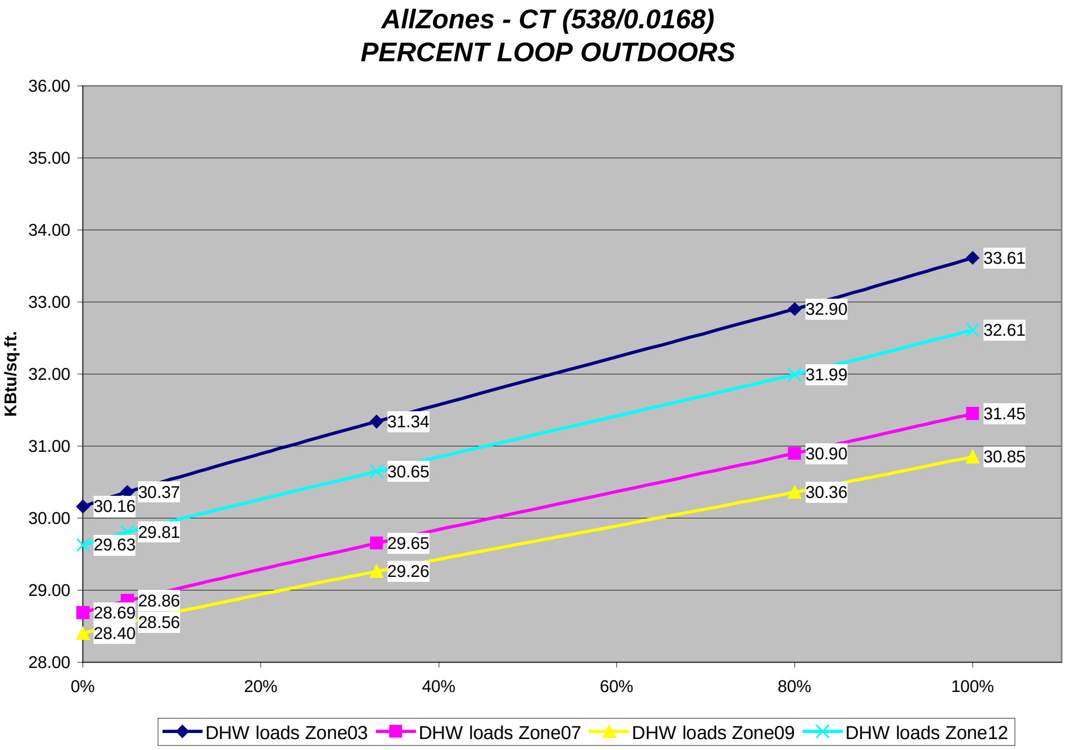

Figure 3: Effect of Climate Zone on Pipe Location Multiplier

In developing the budget, we assumed that all central DHW systems for multifamily buildings have recirculation systems. This assumption is reasonable for a couple reasons. First, we expect that tenants would find the typical delays in delivery of hot water without a re-circulation system to be unacceptable. Studies have shown that some delays associated with appropriate re-circulation controls are acceptable, but that when the controls cause too many delays, tenant dissatisfaction causes property owners to revert to more constant re-circulation (Lobenstein). It is reasonable to assume that if a multifamily building were built without a re-circulating DHW system, there would be enough tenant dissatisfaction to require the building owner to install a pump, thereby negating any assumed energy savings from originally choosing not to. Finally, we believe that the market (MF building developers) has already come to this same conclusion. All the multifamily buildings we examined that had a central water heating system also had a re-circulation loop.

The building DHW description upon which this budget is based, in other words our recommendations for what is assumed in the base case, include a central boiler of minimum efficiency, a distribution loop with a re-circulating pump, a timer control with a seven hour shut-off at night, minimally insulated pipes located 5% outside the envelope and 95% in an unconditioned plenum, an average pipe length/CFA ratio of 0.016, and laundry facilities within the apartments. Each of these factors become variables in computing the Proposed Water Heating Energy Use.

Hourly Water Heating Model for Central DHW

This model is yet to be developed by Eley Associates. The analysis we performed to determine the relative value and effect of central water heating distribution measures will allow us to provide direct assistance in implementing an hourly water heating model. The recommendations above for what should be assumed for the base case in an annual model will be similar, but appropriately modified for an hourly case.

Calculating Proposed DHW Energy

We recommend a set of compliance algorithms that account for piping losses varying by location of the piping, insulation level of the piping, time or temp controls on the re-circulation loop and location of the laundry facilities. Algorithms for the compliance programs should also account for variations in distribution losses by Climate Zone. Likewise, if an hourly water heating budget methodology is adopted, the budget should include this same variation.

In order of impact, the measures that affect water heating energy use in central DHW systems are:

1. Pump control – whether or not there is a control on the re-circulation system (vs. running 24 hours, 365 days/yr.) makes more difference than anything else, but the energy differences between one type of control and another is less than the energy impacts of some other measures.
2. Pipe location – this is outranks all other measures in most climate zones with typical buildings, however, it is less important as the amount of pipe for a specific building (pl/CFA) decreases.
3. Pipe insulation – in cases of very low lp/CFA ratios, pipe insulation makes a larger difference than pipe location, but for average and large values of lp/CFA, pipe insulation is third most important.
4. Type of pump control (timer vs. temperature vs. time/temp.) - at present this ranking is based on our analysis of the other measures and our knowledge of work by others on measuring the effects of various control strategies.
5. Separate laundry facilities – the assumptions for this analysis were that if there was a separate laundry center, then (a) individual hook-ups in apartments did not exist, and (b) the laundry center was placed either right next to the boiler or in some other location that did not add to the amount of distribution piping.
6. The location of the piping if it is outdoors – distribution piping underground tends to cause higher distribution losses but only 1% - 2% more than an equal amount of piping outside the envelope and above ground.

The analyses supporting this ranking and the relative impacts across climate zones are shown in tables and graphs in the Appendices. The form of the multipliers are not provided here because they are subject to a pending decision on whether to maintain the Standard's current approach of setting an annual water heating budget, or to create a new methodology that establishes the budget on an hourly basis. Further, we do not know the form an hourly methodology would take if one is adopted.

Proposed Standards Language

The following are the changes we recommend making to the Standards. These changes are based on an assumption of a continuing commitment to the annual DHW budget equation. Standards language for implementing both a central water heating model and an hourly water heating calculation model will obviously be different. (For clarity, proposed Standards text for each separate section of the Standards is preceded and followed by horizontal lines.):

Section 151(b)1. will become Section 151(b)1.A with minor changes to reflect that it is to be used for single family residences and multifamily residences with individual water heaters. Section 151(b)1. will read:

---

1. **Water heating budget.** The budgets for water heating systems shall be calculated in compliance with either A. or B. below. Water heating budgets for systems serving single residences (including individual residences with individual water heaters in multifamily buildings) shall comply with A. Water heating budgets for systems serving multiple residences (within the same building or in multiple buildings) shall comply with B.

A. Water heating budgets for individual water heating systems. The budgets for individual water heating systems are those calculated from Equation (1-N).

EQUATION (1-N) – ANNUAL INDIVIDUAL WATER HEATING BUDGET (AWB) EQUATION

[REMAINDER UNCHANGED FROM CURRENT STANDARDS]

Add a new Section 151(b)1.B. It would be confusing to the meaning of the following section to have it all underlined so we provide it in plain text. The new section should read:

B. **Water heating budgets for multifamily buildings with central water heating systems.** The budgets for central water heating systems in multifamily buildings (low-rise or high-rise) are those calculated from Equation (1-O).

EQUATION (1-O) – ANNUAL WATER HEATING BUDGET (AWB$_c$) EQUATION FOR MULTIFAMILY BUILDINGS WITH CENTRAL WATER HEATING

$$AWBc(kBtu/yr\cdot sf)=\frac{\sum_{x=1}^{i} n_x\left[(C_{CZ}/CFA_x)+Y_{CZ}\right]}{\sum_{x=1}^{i} n_x}$$

Where

CFA$_x$ = The conditioned floor area of apartments of size *x* in the building,

***n*$_x$** = The number of apartments of type *x* in the building,

C$_{CZ}$ = A constant that is specific to each Climate Zone (see Table 4), and

Y$_{CZ}$ = A constant that is specific to each Climate Zone (see Table 4).

The annual central water heating budget calculated from Equation (1-O) can be met by either:

1. Calculating the energy consumption of the proposed water heating system including all distribution losses using an approved calculation method; or

2. Installing any gas boiler that meets the minimum efficiency requirements of Section 113 with a re-circulating distribution system and a control capable of automatically turning off the circulating pump when hot water is not required. Distribution system piping shall be insulated in accordance with Section 150(j), Table 1-T for re-circulating sections of service water heating systems.

Section 151(f)8. will also need to be amended.

151(f)8. **Water heating systems.** All water heating systems must meet the water heating budgets calculated from Equation (1-N$_I$) (for single residences or individual residences with individual water heaters in multifamily buildings) or Equation (1-N$_C$) (for water heating systems serving multiple residences).

Note 1 to Section 151(f)8: Any gas-type domestic water heater of 50 gallons or less, which is certified as meeting the Appliance Efficiency Standards, and which meets tank insulation requirements of Section 150(j) may be assumed to meet the water heating budget for individual water heating in individual residences.

Note 2 to Section 151(f)8: Any gas boiler that meets the minimum efficiency requirements of Section 113 with a re-circulating distribution system and a control capable of automatically turning off the circulating pump when hot water is not required may be assumed to meet the water heating budget for central water heating systems. Distribution system piping shall be insulated in accordance with Section 150(j), Table 1-T for re-circulating sections of service water heating systems.

Note that these changes seem to require installation of a re-circulation pump, which would obviously make the system use more energy than if it were not re-circulating. However, the requirement really is to install the controls because we assume that (A) even if the system design did not initially include a pump, that tenant dissatisfaction would result in a pump being added and (B) it is standard practice to provide pumping to the distribution loops in multifamily (MF) buildings. Therefore, exempting systems from controls, because the original design did not have a pump to control, would send the wrong signals to the design community.

No changes are proposed to be made to the nonresidential/high-rise residential portions of the Standards.

This proposed Standards language is offered to allow a comparison between the current situation, where central DHW systems in MF buildings are compared to a budget calculated assuming individual water heaters in every apartment, to the proposed situation, wherein MF buildings with central systems will be compared to a budget assuming a central system. We reiterate that there is a parallel proposal by Eley Associates to change the annual water heating budget equation to an hourly budget algorithm. The language we propose would need to be rewritten if the Commission adopts the hourly approach.

Proposed ACM Language

Since there may be a change to the hourly water heating budget methodology, and since the actual form of the hourly approach is not yet known, no recommendations are made at this time on how the ACM should change. We will work with Eley Associates and Commission Staff on developing the algorithms after the Commission decides whether or not to pursue the hourly approach. The work here of establishing a “custom” water heating budget for central systems will provide the baseline information needed to set the equations.

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This work also relies heavily on the work being done by the Davis Energy Group. The hot water draws (loads in gallons) for individual residential units and the buildings were developed by DEG using their HWSim program. This work benefited from experience gained in helping the Commission to establish the existing water heating modeling procedures (1990-92), and in developing new recommendations for improvements in the modeling procedures for single family buildings for 2005.

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Bibliography and Other Research

U.S. Department of the Interior, U.S. Geological Survey .– *National Handbook of Recommended Methods for Water Data Acquisition; Chapter 11.* [http://water.usgs.gov/pubs/chapter11/chapter11D.html] 2002.

Bouchelle, Matthew P., Danny Parker, and Michael T. Anello. *Factors Influencing Water Heating Energy Use and Peak Demand in a Large Scale Residential Monitoring Study.* Florida Solar Energy Center. 2002.

Caldwell, Erin. *A National Study of Laundry-Water Use in Multi-Housing: A Comparison of Use by Residents with In-Apartment Washers and Residents with Common-Area Laundry Rooms.* National Research Center. Boulder, CO. 2001.

Clements, Bruce R., Bill Person, and A.C.S Hyden. *Simulation of a Combined Space and Water Heating System Firing Pellet Fuel for Commercial/Residential Application.* CANMET Energy Technology Center. Nepean, Ontario. 1999.

Davis Energy Group. *Single Family Water Heating Distribution Loss Evaluation Report – Draft.* Eley Associates and California Energy Commission. 2002.

Eley Associates. *Comparison of Water Heating Types Using Time Dependent Valuation (TDV).* Pacific Gas and Electric Company. 2001.

Goldner, Fred, and Norine H. Karins. *DHW Modeling: System Sizing and Selection Criteria – A Study of Baseloads and Seasonal Efficiency: Final Report 99-2.* New York State Energy Research and Development Authority. 1999.

Goldner, Fred, and Norine H. Karins. *DHW Recirculation System Control Strategies: Final Report 99-1.* New York State Energy Research and Development Authority. 1999.

Howard, Bion. *Hot Water: Cool Possibilities.* "Smart Home Owner – Home Systems & Technology Explained." Issue 1: September/October 2001.

Koomey, Jonathan G., Camilla Dunham, and James D. Lutz. *The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the U.S.: A Detailed End-use Treatment.* Lawrence Berkeley National Lab. 1994.

Koomey, Jonathan G., Richard E. Brown, Robert Richey, Francis X. Johnson, Alan H Sanstad, and Leslie Shown. *Residential Sector End-use Forecasting with Epri-REEPS 2.1: Summary Input Assumptions and Results.* Lawrence Berkeley National Lab. 1995.

Lobenstein, Mary S., David L. Bohac, Ted J. Staler, Timothy S. Dunsworth, and Mark W. Hancock. *Measured Savings from Domestic Hot Water Control Strategies in Multifamily Buildings with Recirculation Loops.* Minnesota Center for Energy and Environment. 1992.

Lobenstein, M.S., D.L. Bohac, T.J. Staller,, T.S. Dunsworth, and M.W. Hancock. *Measured Savings from Time- or Demand-Based Temperature Controls on Service Water Heaters in Apartment Buildings.* Energy Resource Center of St. Paul,MN. 1992

Lutz, James D., Xiaomin Liu, James E. McMahon, Camilla Dunham, Leslie J. Shown, and Quandra T. McGrue. *Modeling Patterns of Hot Water Use in Households.* Lawrence Berkeley National Lab. 1996

Lutz, Jim. *Energy Advisor: About the Water Heating Module.* Lawrence Berkeley national Lab. (January 2002 download from LBNL web site energy advisor program)

Perlman, M., and N.H. Milligan. *Hot Water and Energy Use in Apartment Buildings.* ASHRAE Transactions. 1988.

Sezgen, Osman, and Jonathan G. Koomey. *Technology Data Characterizing Water heating in Commercial Buildings: Application to End-use Forecasting.* Lawrence Berkeley National Lab. 1995.

Stewart, William E., Charles K. Saunders, Carol L. G. Dona. *Evaluation of Service Hot Water Distribution System Losses in residential and Commercial Installations: Part 1 – Field/Laboratory Experiments and Simulation Model.* ASHRAE Transactions. 1999.

Stewart, William E., Charles K. Saunders, Carol L. G. Dona. *Evaluation of Service Hot Water Distribution System Losses in residential and Commercial Installations: Part 2 –Simulations and Design Practices*. ASHRAE Transactions. 1999.

Appendices

A. Complete List of Results of Parametric Runs with Descriptions

B. Graphs of Results From Parametric Runs

C. Summary of Results from Parametric Runs

D. Hourly Domestic Hot Water Load Calculations

E. Recommendations for future research to resolve unresolved issues

Appendix A. Complete List of Results of Parametric Runs with Descriptions

The results of all simulation runs done using DOE2.2 are presented here. A set of eighteen parametric runs, including a Base Case run were made for each of the three buildings analyzed. These parametric cases were analyzed in four climate zones each. (Climate Zone 03, 07, 09, 12). These Climate Zones were chosen because (1) they represent the areas of the state where most of the large multifamily construction is taking place, (2) they form a good representation of the various climate conditions in the state, and (3) limiting the analysis to four representative CZs was a cost effective way to estimate the statewide effects of the measures being analyzed.

The three buildings we used for prototypes are listed in Figure 2 as buildings #2, #11, and #13. The abbreviations for the name of the buildings are also used in some of the following tables and graphs. Buildings #2 is “CT.” Building #11 is “CBC.” Building #13 is “LR.”

CZ 03

Building: CBC

1038.0682 <-- Ave. area of each appt.
91350 <-- Total Building Area (sf)
1100 <-- Pipe Length (ft.)
88 <-- Number of Appts
0.0120 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	28.3	277.3	7.5	29.6	2124.8	3800.6	569.3	959.5	1531.9	225.7	6.2	23.3	41.6
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	27.4	279.8	7.5	29.9	2111.2	3788.8	560.1	959.5	1521.9	225.7	6.1	23.1	41.5
33% piping outdoors	33.4	262.3	7.6	28.1	2159.7	3824.1	594.6	959.5	1557.3	225.7	6.5	23.6	41.9
80% piping outdoors	44.0	238.7	7.7	25.7	2199.5	3848.7	623.4	959.5	1586.3	225.7	6.8	24.1	42.1
All piping outdoors	49.9	227.4	8.1	24.6	2327.8	3970.9	717.3	959.5	1680.1	225.7	7.9	25.5	43.5
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	30.0	269.7	7.2	28.9	2018.7	3687.6	491.7	959.5	1454.4	225.7	5.4	22.1	40.4
Insulation is 1.5" (all piping outdoors)	49.9	227.4	7.7	24.6	2191.6	3834.3	617.5	959.5	1580.6	225.7	6.8	24.0	42.0
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	32.9	254.9	5.9	27.3	1812.3	3466.3	344.5	959.5	1303.7	0.0	3.8	19.8	37.9
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	28.8	270.8	7.1	29.0	2059.2	3728.0	516.8	959.5	1484.0	172.6	5.7	22.5	40.8
Peak ShutOff 8am-10am 4pm-6pm	22.4	273.5	7.9	29.2	2227.8	3893.9	643.4	959.5	1607.1	265.5	7.0	24.4	42.6
Washing Energy													
Same Water Heater , Separate Loop	29.0	276.3	7.4	29.5	2104.2	3779.5	554.5	788.1	1516.8	225.7	6.1	23.0	41.4
Seperate Water Heater , Separate Loop	29.1	276.2	13.5	29.5	2143.2	3824.6	553.0	788.1	1343.7	225.7	6.1	23.5	41.9
								Washing loop Heater -->	171.0				
% Loop UnderGround													
5% piping underground	28.3	277.3	7.5	29.6	2124.8	3800.6	569.3	959.5	1531.9	225.7	6.2	23.3	41.6
1/3rd piping underground	32.9	262.0	7.6	28.1	2166.7	3830.3	599.9	959.5	1562.4	225.7	6.6	23.7	41.9
80% piping underground	43.8	238.5	7.8	25.7	2214.9	3863.8	634.9	959.5	1597.6	225.7	7.0	24.2	42.3
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
70 Units	28.8	276.6	7.0	29.6	1953.4	3628.5	558.7	845.3	1406.7	225.7	6.1	21.4	39.7
115 Units	27.7	277.9	8.2	29.7	2358.3	4034.7	582.2	1116.7	1702.3	225.7	6.4	25.8	44.2
Recirc Pump Always On													
Recirc Pump Always On	21.8	279.4	8.3	29.8	2295.8	3968.2	697.5	959.5	1656.7	318.6	7.6	25.1	43.4

Figure 4: Climate Zone 3, Building: CBC

CZ 03

Building: CT

32027 <-- Total Building Area (sf)
54 <-- Number of Appts
593.09259 <-- Ave. area of each appt.
538 <-- Pipe Length (ft.)
0.0168 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.5	174.6	12.4	10.2	972.5	1653.4	280.2	496.6	777.9	70.6	8.7	30.4	51.6
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.4	179.1	12.3	10.5	966.0	1651.5	275.3	496.6	772.7	70.6	8.6	30.2	51.6
33% piping outdoors	1.2	151.9	12.7	8.8	1003.8	1662.2	305.1	496.6	802.9	70.6	9.5	31.3	51.9
80% piping outdoors	2.1	124.9	13.3	7.3	1053.8	1685.6	345.2	496.6	842.9	70.6	10.8	32.9	52.6
All piping outdoors	2.4	116.2	13.6	6.7	1076.5	1699.7	363.4	496.6	861.1	70.6	11.3	33.6	53.1
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.7	164.2	11.7	9.6	917.5	1587.1	236.2	496.6	733.9	70.6	7.4	28.6	49.6
Insulation is 1.5" (all piping outdoors)	2.4	116.2	12.7	6.7	1002.5	1624.8	304.0	496.6	801.9	70.6	9.5	31.3	50.7
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	0.8	155.1	11.0	9.0	877.0	1536.4	205.1	496.6	701.5	0.0	6.4	27.4	48.0
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.5	169.5	12.1	9.9	953.0	1628.2	263.1	496.6	762.3	54.0	8.2	29.8	50.8
Peak ShutOff 8am-10am 4pm-6pm	0.1	176.4	12.9	10.3	1011.6	1693.9	311.3	496.6	809.2	83.1	9.7	31.6	52.9
Washing Energy													
Same Water Heater , Separate Loop	0.6	173.0	12.0	10.1	938.7	1617.8	271.8	422.6	750.9	70.6	8.5	29.3	50.5
Seperate Water Heater , Separate Loop	0.6	172.8	17.6	10.1	947.2	1631.8	270.7	422.6	694.3	70.6	8.5	29.6	51.0
								Washing loop Heater -->	55.3				
% Loop UnderGround													
5% piping underground	0.5	174.5	12.4	10.2	972.8	1653.6	280.5	496.6	778.2	70.6	8.8	30.4	51.6
1/3rd piping underground	1.1	151.4	12.8	8.8	1006.6	1664.4	307.5	496.6	805.2	70.6	9.6	31.4	52.0
80% piping underground	2.0	124.7	13.4	7.2	1060.2	1691.7	350.4	496.6	848.1	70.6	10.9	33.1	52.8
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
24 Units	0.8	168.5	8.8	9.8	675.3	1346.8	249.8	289.6	540.1	70.6	7.8	21.1	42.1
30 Units	0.7	170.3	9.6	9.9	741.8	1415.8	257.5	335.0	593.3	70.6	8.0	23.2	44.2
Recirc Pump Always On													
Recirc Pump Always On	0.1	181.7	13.2	10.6	1031.7	1719.8	328.8	496.6	825.3	99.7	10.3	32.2	53.7

Figure 5: Climate Zone 3, Building: CT

CZ 03

Building: LR

1334.5978 <-- Ave. area of each appt.

122783 <-- Total Building Area (sf)

2342 <-- Pipe Length (ft.)

92 <-- Number of Appts

0.0191 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.8	308.9	14.6	15.7	3049.5	4703.6	1176.0	1122.4	2306.8	955.9	9.6	24.8	38.3
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.7	310.3	14.5	15.8	2967.5	4622.8	1023.5	1122.4	2239.7	955.9	8.3	24.2	37.7
33% piping outdoors	2.1	236.2	14.8	12.0	3229.1	4809.7	1270.1	1122.4	2453.7	955.9	10.3	26.3	39.2
80% piping outdoors	4.8	159.3	15.0	8.2	3384.6	4889.7	1449.8	1122.4	2580.9	955.9	11.8	27.6	39.8
All piping outdoors	6.1	137.8	15.1	7.2	3480.0	4964.9	1526.7	1122.4	2659.0	955.9	12.4	28.3	40.4
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.9	271.2	14.4	13.8	2797.8	4412.4	897.0	1122.4	2100.8	955.9	7.3	22.8	35.9
Insulation is 1.5" (all piping outdoors)	6.1	137.8	14.7	7.2	3136.4	4620.9	1152.0	1122.4	2377.9	955.9	9.4	25.5	37.6
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	2.0	194.5	10.5	9.9	2261.5	3794.2	542.0	1122.4	1662.0	0.0	4.4	18.4	30.9
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.8	269.6	13.7	13.7	2865.0	4477.0	1011.3	1122.4	2156.0	730.9	8.2	23.3	36.5
Peak ShutOff 8am-10am 4pm-6pm	0.1	273.6	15.5	13.9	3297.6	4913.3	1376.0	1122.4	2509.8	1124.5	11.2	26.9	40.0
Washing Energy													
Same Water Heater , Separate Loop	0.8	308.8	14.6	15.7	3042.1	4696.1	1171.9	1120.6	2300.8	955.9	9.5	24.8	38.2
Seperate Water Heater , Separate Loop	0.8	308.7	16.7	15.7	3067.4	4723.5	1170.2	1120.6	2234.2	955.9	9.5	25.0	38.5
							Washing loop Heater -->		65.6				
% Loop UnderGround													
5% piping underground	0.7	308.7	14.6	15.7	3051.7	4705.6	1178.0	1122.4	2308.6	955.9	9.6	24.9	38.3
1/3rd piping underground	1.9	235.5	14.8	12.0	3247.9	4827.6	1338.0	1122.4	2469.2	955.9	10.9	26.5	39.3
80% piping underground	4.6	159.0	15.0	8.2	3422.1	4926.6	1481.0	1122.4	2611.6	955.9	12.1	27.9	40.1
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
109 nits	0.7	309.1	14.7	15.8	3154.3	4808.7	1181.6	1202.6	2392.5	955.9	9.6	25.7	39.2
176 Units	0.6	310.4	15.4	15.8	3768.3	5424.3	1216.6	1668.6	2895.0	955.9	9.9	30.7	44.2
Recirc Pump Always On													
Recirc Pump Always On	0.1	313.3	16.4	15.9	3482.5	5140.9	1541.0	1122.4	2661.0	1349.4	12.6	28.4	41.9

Figure 6: Climate Zone 3, Building: LR

CZ 07

Building: CBC

1038.0682 <-- Ave. area of each appt.
91350 <-- Total Building Area (sf)
1100 <-- Pipe Length (ft.)
88 <-- Number of Appts
0.0120 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
5% of piping is outdoors (Primary Loop)	1.4	504.6	6.7	52.9	2017.7	3916.4	553.3	898.8	1454.9	225.7	6.1	22.1	42.9
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	1.3	508.6	6.7	53.3	2006.7	3909.7	545.9	898.8	1446.8	225.7	6.0	22.0	42.8
33% piping outdoors	1.9	481.6	6.8	50.6	2041.4	3915.3	570.5	898.8	1472.2	225.7	6.2	22.3	42.9
80% piping outdoors	2.5	439.7	6.9	46.3	2064.4	3892.7	586.9	898.8	1488.9	225.7	6.4	22.6	42.6
All piping outdoors	2.8	422.1	7.2	44.5	2178.1	3987.8	670.3	898.8	1572.0	225.7	7.3	23.8	43.7
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	1.5	492.7	6.4	51.7	1914.5	3799.8	477.7	898.8	1379.5	225.7	5.2	21.0	41.6
Insulation is 1.5" (all piping outdoors)	2.8	422.1	6.8	44.5	2051.0	3860.3	577.2	898.8	1479.2	225.7	6.3	22.5	42.3
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	1.7	468.6	5.1	49.2	1714.7	3572.4	335.3	898.8	1233.7	0.0	3.7	18.8	39.1
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	1.4	494.0	6.4	51.8	1953.9	3840.6	502.3	898.8	1408.3	172.6	5.5	21.4	42.0
Peak ShutOff 8am-10am 4pm-6pm	1.0	501.5	7.2	52.6	2118.5	4013.8	625.8	898.8	1528.5	265.5	6.9	23.2	43.9
Washing Energy													
Same Water Heater , Separate Loop	1.4	503.1	6.7	52.8	1997.5	3894.5	538.8	738.2	1440.1	225.7	5.9	21.9	42.6
Seperate Water Heater , Separate Loop	1.4	503.0	12.8	52.8	2033.9	3937.0	537.5	738.2	1278.0	225.7	5.9	22.3	43.1
							Washing loop Heater -->		160.1				
% Loop UnderGround													
5% piping underground	1.4	504.6	6.7	52.9	2017.7	3916.4	553.3	898.8	1454.9	225.7	6.1	22.1	42.9
1/3rd piping underground	1.9	481.4	6.8	50.5	2048.8	3922.5	576.1	898.8	1477.6	225.7	6.3	22.4	42.9
80% piping underground	2.4	439.4	6.9	46.2	2080.6	3908.7	599.0	898.8	1500.8	225.7	6.6	22.8	42.8
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
70 Units	1.4	503.6	6.3	52.8	1856.6	3753.7	543.0	791.7	1337.2	225.7	5.9	20.3	41.1
115 Units	1.3	505.8	7.3	53.1	2237.0	4137.5	565.9	1045.9	1615.0	225.7	6.2	24.5	45.3
Recirc Pump Always On													
Recirc Pump Always On	1.0	511.5	7.5	53.6	2184.7	4091.3	678.5	898.8	1576.8	318.6	7.4	23.9	44.8

Figure 7: Climate Zone 7, Building: CBC

CZ 07

Building: CT

593.09259 <-- Ave. area of each appt.
32027 <-- Total Building Area (sf)
538 <-- Pipe Length (ft.)
54 <-- Number of Appts
0.0168 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.0	337.7	11.5	19.8	924.2	1775.4	273.1	465.1	739.3	70.6	8.5	28.9	55.4
Heater is Outdoors											0.0	0.0	0.0
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.0	344.8	11.4	20.2	918.8	1777.5	269.1	465.1	735.0	70.6	8.4	28.7	55.5
33% piping outdoors	0.1	303.2	11.8	17.6	949.7	1764.7	293.4	465.1	759.7	70.6	9.2	29.7	55.1
80% piping outdoors	0.1	264.5	12.2	15.3	989.6	1764.2	325.4	465.1	791.6	70.6	10.2	30.9	55.1
All piping outdoors	0.2	251.5	12.5	14.5	1007.3	1768.3	339.5	465.1	805.7	70.6	10.6	31.5	55.2
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.0	323.4	10.8	18.9	870.5	1706.0	230.1	465.1	696.4	70.6	7.2	27.2	53.3
Insulation is 1.5" (all piping outdoors)	0.2	251.5	11.6	14.5	938.2	1698.4	284.1	465.1	750.5	70.6	8.9	29.3	53.0
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	0.0	310.5	10.1	18.1	831.3	1652.3	200.0	465.1	665.0	0.0	6.2	26.0	51.6
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.0	330.8	11.2	19.3	905.2	1748.7	256.5	465.1	724.1	54.0	8.0	28.3	54.6
Peak ShutOff 8am-10am 4pm-6pm	0.0	344.5	12.0	20.2	962.5	1821.3	303.6	465.1	770.0	83.1	9.5	30.1	56.9
Washing Energy													
Same Water Heater , Separate Loop	0.0	335.2	11.1	19.6	892.1	1740.2	264.9	395.9	713.6	70.6	8.3	27.9	54.3
Seperate Water Heater , Separate Loop	0.0	334.8	16.8	19.6	900.1	1753.6	263.8	395.9	660.6	70.6	8.2	28.1	54.8
							Washing loop Heater -->		51.8				
% Loop UnderGround													
5% piping underground	0.0	337.8	11.5	19.8	924.5	1775.8	273.5	465.1	739.6	70.6	8.5	28.9	55.4
1/3rd piping underground	0.1	303.0	11.8	17.6	952.7	1767.5	296.0	465.1	762.1	70.6	9.2	29.7	55.2
80% piping underground	0.1	264.4	12.3	15.3	996.5	1771.0	331.1	465.1	797.2	70.6	10.3	31.1	55.3
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
24 Units	0.1	327.9	8.1	19.2	644.4	1481.9	243.5	271.3	515.4	70.6	7.6	20.1	46.3
30 Units	0.0	330.1	8.9	19.3	707.0	1547.6	251.0	313.8	565.5	70.6	7.8	22.1	48.3
Recirc Pump Always On													
Recirc Pump Always On	0.0	351.6	12.3	20.6	982.1	1848.6	320.7	465.1	785.6	99.7	10.0	30.7	57.7

Figure 8: Climate Zone 7, Building: CT

CZ 07

Building: LR

1334.5978 <-- Ave. area of each appt.
122783 <-- Total Building Area (sf)
2342 <-- Pipe Length (ft.)
92 <-- Number of Appts
0.0191 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.0	575.7	9.8	29.1	2920.3	4847.5	1146.0	1051.2	2204.9	955.9	9.3	23.8	39.5
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.0	579.0	9.7	29.3	2841.8	4772.3	1085.4	1051.2	2140.6	955.9	8.8	23.1	38.9
33% piping outdoors	0.1	466.3	9.9	23.5	3068.2	4880.6	1266.1	1051.2	2325.9	955.9	10.3	25.0	39.7
80% piping outdoors	0.1	344.5	10.1	17.3	3185.9	4870.5	1362.3	1051.2	2422.2	955.9	11.1	25.9	39.7
All piping outdoors	0.1	308.1	10.1	15.4	3264.5	4911.0	1426.3	1051.2	2486.5	955.9	11.6	26.6	40.0
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.0	521.0	9.5	26.3	2675.1	4544.5	945.0	1051.2	2004.1	955.9	7.7	21.8	37.0
Insulation is 1.5" (all piping outdoors)	0.1	308.1	9.8	15.4	2943.8	4590.0	1163.9	1051.2	2224.1	955.9	9.5	24.0	37.4
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	0.0	406.9	5.7	20.4	2153.3	3898.9	173.4	509.5	1577.3	0.0	1.4	17.5	31.8
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.0	525.4	8.8	26.5	2740.5	4613.8	985.2	1051.2	2057.7	730.9	8.0	22.3	37.6
Peak ShutOff 8am-10am 4pm-6pm	0.0	559.3	10.6	28.3	3162.6	5073.2	1341.0	1051.2	2403.0	1124.5	10.9	25.8	41.3
Washing Energy													
Same Water Heater , Separate Loop	0.0	575.2	9.8	29.1	2913.1	4839.8	1141.4	1049.8	2199.0	955.9	9.3	23.7	39.4
Seperate Water Heater , Separate Loop	0.0	575.1	11.9	29.1	2936.9	4865.5	1139.9	1049.8	2136.7	955.9	9.3	23.9	39.6
							Washing loop Heater -->		61.5				
% Loop UnderGround													
5% piping underground	0.0	575.6	9.8	29.1	2922.7	4849.7	1148.3	1051.2	2206.8	955.9	9.4	23.8	39.5
1/3rd piping underground	0.1	465.8	10.0	23.5	3088.0	4900.0	1282.9	1051.2	2342.2	955.9	10.4	25.2	39.9
80% piping underground	0.1	344.3	10.1	17.3	3225.0	4909.5	1395.4	1051.2	2454.3	955.9	11.4	26.3	40.0
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
109 nits	0.0	576.4	9.9	29.2	3018.6	4946.6	1151.1	1126.3	2285.4	955.9	9.4	24.6	40.3
176 Units	0.0	580.4	10.5	29.4	3595.6	5528.4	1185.0	1563.0	2757.5	955.9	9.7	29.3	45.0
Recirc Pump Always On													
Recirc Pump Always On	0.0	609.7	11.6	30.9	3342.7	5307.3	1501.7	1051.2	2550.4	1349.4	12.2	27.2	43.2

Figure 9: Climate Zone 7, Building: LR

CZ 09

Building: CBC

1038.0682 <-- Ave. area of each appt.
91350 <-- Total Building Area (sf)
1100 <-- Pipe Length (ft.)
88 <-- Number of Appts
0.0120 <-- Pipe Length per sq.ft. (ft.)

CASES		SIMULATION RESULTS												
		Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description		Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE														
Insulation is 1"														
5% of piping is outdoors (Primary Loop)		3.2	679.2	6.8	69.0	1996.1	4087.4	552.0	884.6	1439.4	225.7	6.0	21.9	44.7
Heater is Outdoors														
With Recirc Pump														
Night ShutOff on Recirc Time Control														
Same DWH for washing energy														
% Loop Outdoors														
All piping in Plenum		3.1	683.9	6.8	69.5	1986.3	4082.6	545.4	884.6	1432.2	225.7	6.0	21.7	44.7
33% piping outdoors		3.7	654.8	6.9	66.5	2013.4	4078.3	564.4	884.6	1452.0	225.7	6.2	22.0	44.6
80% piping outdoors		5.1	613.0	6.9	62.3	2027.0	4047.4	574.1	884.6	1462.0	225.7	6.3	22.2	44.3
All piping outdoors		6.0	594.3	7.2	60.4	2135.8	4136.7	653.7	884.6	1541.4	225.7	7.2	23.4	45.3
Loop R Value														
Insulation is 1.5" (5% piping outdoors)		3.3	666.0	6.5	67.7	1893.2	3969.7	476.6	884.6	1364.3	225.7	5.2	20.7	43.5
Insulation is 1.5" (all piping outdoors)		6.0	594.3	6.9	60.4	2012.3	4012.8	563.3	884.6	1451.2	225.7	6.2	22.0	43.9
No Recirc Pump														
Recirc Pump removed - 5% piping outdoors		3.7	641.8	5.2	65.2	1694.2	3743.1	334.9	884.6	1219.0	0.0	3.7	18.5	41.0
Time Control														
Nights & Peak ShutOff	11pm-6am 8am-10am 4pm-6pm	3.2	668.0	6.5	67.9	1932.2	4010.8	500.9	884.6	1392.7	172.6	5.5	21.2	43.9
Peak ShutOff	8am-10am 4pm-6pm	2.1	675.5	7.2	68.6	2096.9	4183.4	624.6	884.6	1513.0	265.5	6.8	23.0	45.8
Washing Energy														
Same Water Heater , Separate Loop		3.3	677.5	6.8	68.8	1975.9	4065.3	537.5	726.6	1424.7	225.7	5.9	21.6	44.5
Seperate Water Heater , Separate Loop		3.3	677.3	12.8	68.8	2011.7	4106.9	536.1	726.6	1265.1	225.7	5.9	22.0	45.0
								Washing loop Heater -->		157.6				
% Loop UnderGround														
5% piping underground		3.2	679.2	6.8	69.0	1996.1	4087.4	552.0	884.6	1439.4	225.7	6.0	21.9	44.7
1/3rd piping underground		3.6	654.4	6.9	66.5	2023.9	4088.4	572.3	884.6	1459.7	225.7	6.3	22.2	44.8
80% piping underground		5.1	612.8	7.0	62.3	2050.1	4070.3	591.2	884.6	1478.9	225.7	6.5	22.4	44.6
Temp Control														
Pump Shutoff														
Water heater output control														
Time / Temp Control														
Demand based controls														
Changed No.of Units														
70 Units		3.2	677.9	6.4	68.9	1837.3	3926.8	541.6	779.3	1323.5	225.7	5.9	20.1	43.0
115 Units		3.1	681.0	7.4	69.2	2212.2	4306.1	564.5	1029.5	1597.2	225.7	6.2	24.2	47.1
Recirc Pump Always On														
Recirc Pump Always On		2.0	686.5	7.6	69.8	2163.1	4262.0	677.2	884.6	1561.3	318.6	7.4	23.7	46.7

Figure 10: Climate Zone 9, Building: CBC

CZ 09

Building: CT

593.09259 <-- Ave. area of each appt.
32027 <-- Total Building Area (sf)
538 <-- Pipe Length (ft.)
54 <-- Number of Appts
0.0168 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.0	392.0	11.5	22.8	914.6	1823.0	272.8	457.8	731.6	70.6	8.5	28.6	56.9
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.0	399.1	11.4	23.2	909.6	1825.5	269.1	457.8	727.6	70.6	8.4	28.4	57.0
33% piping outdoors	0.1	361.6	11.7	20.9	937.2	1813.8	290.7	457.8	749.7	70.6	9.1	29.3	56.6
80% piping outdoors	0.2	322.6	12.1	18.5	972.4	1808.3	318.9	457.8	777.9	70.6	10.0	30.4	56.5
All piping outdoors	0.2	309.5	12.3	17.7	988.1	1810.4	331.5	457.8	790.5	70.6	10.4	30.9	56.5
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.0	379.1	10.8	21.9	860.9	1755.0	229.8	457.8	688.7	70.6	7.2	26.9	54.8
Insulation is 1.5" (all piping outdoors)	0.2	309.5	11.5	17.7	920.9	1742.4	277.6	457.8	736.7	70.6	8.7	28.8	54.4
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	0.0	368.0	10.1	21.2	821.9	1703.4	199.8	457.8	657.4	0.0	6.2	25.7	53.2
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.0	385.8	11.2	22.4	895.5	1797.0	256.0	457.8	716.3	54.0	8.0	28.0	56.1
Peak ShutOff 8am-10am 4pm-6pm	0.0	398.7	12.0	23.2	952.9	1868.8	303.3	457.8	762.3	83.1	9.5	29.8	58.4
Washing Energy													
Same Water Heater , Separate Loop	0.0	389.4	11.1	22.6	882.8	1788.1	264.5	389.6	706.2	70.6	8.3	27.6	55.8
Seperate Water Heater , Separate Loop	0.0	389.2	16.7	22.6	890.6	1801.3	263.4	389.6	653.9	70.6	8.2	27.8	56.2
							Washing loop Heater -->		51.0				
% Loop UnderGround													
5% piping underground	0.0	392.0	11.5	22.8	915.0	1823.5	273.3	457.8	731.9	70.6	8.5	28.6	56.9
1/3rd piping underground	0.1	361.2	11.8	20.8	941.5	1817.6	294.3	457.8	753.1	70.6	9.2	29.4	56.8
80% piping underground	0.2	322.1	12.3	18.4	982.1	1817.6	326.8	457.8	785.6	70.6	10.2	30.7	56.8
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
24 Units	0.0	383.2	8.2	22.2	638.5	1534.4	243.0	267.0	510.7	70.6	7.6	19.9	47.9
30 Units	0.0	385.4	8.9	22.4	700.3	1599.2	250.6	308.8	560.2	70.6	7.8	21.9	49.9
Recirc Pump Always On													
Recirc Pump Always On	0.0	405.1	12.2	23.6	972.5	1895.5	320.3	457.8	778.0	99.7	10.0	30.4	59.2

Figure 11: Climate Zone 9, Building: CT

CZ 09

Building: LR

1334.5978 <-- Ave. area of each appt.
122783 <-- Total Building Area (sf)
2342 <-- Pipe Length (ft.)
92 <-- Number of Appts
0.0191 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	0.0	836.5	11.2	40.9	2893.8	5094.9	1141.0	1035.0	2184.1	955.9	9.3	23.6	41.5
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	0.0	839.6	11.2	41.1	2816.7	5020.9	1082.0	1035.0	2121.0	955.9	8.8	22.9	40.9
33% piping outdoors	0.0	727.7	11.4	35.5	3024.8	5111.9	1248.0	1035.0	2291.3	955.9	10.2	24.6	41.6
80% piping outdoors	0.1	603.2	11.5	29.2	3123.6	5080.2	1328.8	1035.0	2372.2	955.9	10.8	25.4	41.4
All piping outdoors	0.2	564.5	11.6	27.3	3195.4	5111.6	1387.0	1035.0	2430.9	955.9	11.3	26.0	41.6
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	0.0	782.3	11.0	38.2	2649.2	4793.1	942.0	1035.0	1983.9	955.9	7.7	21.6	39.0
Insulation is 1.5" (all piping outdoors)	0.2	564.5	11.2	27.3	2884.6	4800.5	1133.0	1035.0	2176.6	955.9	9.2	23.5	39.1
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	0.0	668.8	7.2	32.5	2129.2	4150.1	526.1	1035.0	1558.5	0.0	4.3	17.3	33.8
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	0.0	785.6	10.3	38.3	2713.9	4860.6	981.0	1035.0	2036.9	730.9	8.0	22.1	39.6
Peak ShutOff 8am-10am 4pm-6pm	0.0	820.2	12.1	40.1	3136.4	5321.1	1337.0	1035.0	2382.4	1124.5	10.9	25.5	43.3
Washing Energy													
Same Water Heater , Separate Loop	0.0	835.9	11.2	40.9	2886.7	5087.2	1137.1	1033.8	2178.3	955.9	9.3	23.5	41.4
Seperate Water Heater , Separate Loop	0.0	835.8	13.3	40.9	2910.1	5112.5	1135.8	1033.8	2116.9	955.9	9.3	23.7	41.6
							Washing loop Heater -->		60.5				
% Loop UnderGround													
5% piping underground	0.0	836.4	11.2	40.9	2897.3	5098.3	1145.0	1035.0	2187.0	955.9	9.3	23.6	41.5
1/3rd piping underground	0.0	727.3	11.4	35.4	3053.3	5139.9	1272.0	1035.0	2314.6	955.9	10.4	24.9	41.9
80% piping underground	0.1	603.0	11.6	29.2	3179.7	5136.1	1375.6	1035.0	2418.0	955.9	11.2	25.9	41.8
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
109 nits	0.0	837.1	11.3	41.0	2990.7	5192.6	1147.0	1109.2	2263.4	955.9	9.3	24.4	42.3
176 Units	0.0	841.1	12.0	41.2	3559.3	5765.9	1180.8	1538.3	2728.7	955.9	9.6	29.0	47.0
Recirc Pump Always On													
Recirc Pump Always On	0.0	871.3	13.0	42.7	3316.8	5556.2	1497.9	1035.0	2530.1	1349.4	12.2	27.0	45.3

Figure 12: Climate Zone 9, Building: LR

CZ 12

Building: CBC

1038.0682 <-- Ave. area of each appt.
91350 <-- Total Building Area (sf)
1100 <-- Pipe Length (ft.)
88 <-- Number of Appts
0.0120 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	117.8	624.6	7.8	63.1	2085.8	4232.2	565.8	935.1	1503.9	225.7	6.2	22.8	46.3
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	114.4	628.0	7.8	63.4	2074.0	4220.7	557.9	935.1	1495.2	225.7	6.1	22.7	46.2
33% piping outdoors	135.6	605.3	7.9	61.3	2111.0	4254.2	583.9	935.1	1522.3	225.7	6.4	23.1	46.6
80% piping outdoors	169.2	571.9	8.0	58.2	2136.9	4277.2	602.6	935.1	1541.1	225.7	6.6	23.4	46.8
All piping outdoors	185.6	557.0	8.3	56.8	2257.2	4397.9	690.6	935.1	1629.0	225.7	7.6	24.7	48.1
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	124.8	614.3	7.6	62.1	1980.4	4122.2	488.5	935.1	1426.9	225.7	5.3	21.7	45.1
Insulation is 1.5" (all piping outdoors)	185.6	557.0	8.0	56.8	2126.7	4267.1	595.0	935.1	1533.7	225.7	6.5	23.3	46.7
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	136.2	594.9	6.2	60.3	1775.8	3906.4	342.8	935.1	1277.5	0.0	3.8	19.4	42.8
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	120.2	615.6	7.5	62.2	2020.4	4158.9	513.4	935.1	1456.1	172.6	5.6	22.1	45.5
Peak ShutOff 8am-10am 4pm-6pm	96.4	620.4	8.3	62.5	2189.2	4309.9	640.3	935.1	1579.4	265.5	7.0	24.0	47.2
Washing Energy													
Same Water Heater , Separate Loop	120.3	623.6	7.8	63.0	2065.2	4213.0	551.0	768.1	1488.8	225.7	6.0	22.6	46.1
Seperate Water Heater , Separate Loop	120.5	623.4	13.6	63.0	2103.1	4256.6	549.5	768.1	1320.1	225.7	6.0	23.0	46.6
							Washing loop Heater -->		-166.6				
% Loop UnderGround													
5% piping underground	117.8	624.6	7.8	63.1	2085.8	4232.2	565.8	935.1	1503.9	225.7	6.2	22.8	46.3
1/3rd piping underground	134.5	604.9	8.0	61.3	2122.4	4264.0	592.5	935.1	1530.6	225.7	6.5	23.2	46.7
80% piping underground	168.2	571.6	8.1	58.2	2161.9	4300.9	621.2	935.1	1559.4	225.7	6.8	23.7	47.1
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
70 Units	119.6	623.9	7.4	63.1	1918.4	4065.4	555.2	823.7	1381.7	225.7	6.1	21.0	44.5
115 Units	115.8	625.8	8.5	63.2	2313.8	4460.1	578.6	1088.2	1670.3	225.7	6.3	25.3	48.8
Recirc Pump Always On													
Recirc Pump Always On	92.6	629.0	8.6	63.4	2256.9	4383.6	694.1	935.1	1628.8	318.6	7.6	24.7	48.0

Figure 13: Climate Zone 12, Building: CBC

CZ 12

Building: CT

593.09259 <-- Ave. area of each appt.
32027 <-- Total Building Area (sf)
538 <-- Pipe Length (ft.)
54 <-- Number of Appts
0.0168 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	3.1	327.0	12.4	18.8	954.7	1802.5	278.7	483.9	763.7	70.6	8.7	29.8	56.3
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	2.6	331.8	12.4	19.1	948.9	1801.0	274.4	483.9	759.1	70.6	8.6	29.6	56.2
33% piping outdoors	5.4	306.1	12.8	17.6	981.6	1811.2	300.0	483.9	785.2	70.6	9.4	30.6	56.6
80% piping outdoors	8.3	278.2	13.3	16.1	1024.6	1829.5	334.4	483.9	819.6	70.6	10.4	32.0	57.1
All piping outdoors	9.0	268.5	13.5	15.5	1044.4	1840.4	350.3	483.9	835.4	70.6	10.9	32.6	57.5
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	3.5	317.7	11.8	18.3	900.0	1738.0	234.8	483.9	719.9	70.6	7.3	28.1	54.3
Insulation is 1.5" (all piping outdoors)	9.0	268.5	12.7	15.5	973.4	1768.5	293.3	483.9	778.6	70.6	9.2	30.4	55.2
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	3.9	309.7	11.1	17.8	859.8	1689.3	203.9	483.9	687.7	0.0	6.4	26.8	52.7
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	3.1	322.8	12.2	18.5	935.3	1778.2	261.6	483.9	748.1	54.0	8.2	29.2	55.5
Peak ShutOff 8am-10am 4pm-6pm	1.4	331.3	13.0	19.0	994.0	1843.3	309.9	483.9	795.1	83.1	9.7	31.0	57.6
Washing Energy													
Same Water Heater , Separate Loop	3.3	325.4	12.1	18.7	921.6	1767.7	270.3	411.9	737.2	70.6	8.4	28.8	55.2
Seperate Water Heater , Separate Loop	3.3	325.3	17.5	18.7	929.8	1781.3	269.2	411.9	682.0	70.6	8.4	29.0	55.6
							Washing loop Heater -->		53.9				
% Loop UnderGround													
5% piping underground	3.0	327.0	12.5	18.8	955.2	1802.8	279.2	483.9	764.1	70.6	8.7	29.8	56.3
1/3rd piping underground	5.0	305.5	12.8	17.6	986.2	1814.7	303.8	483.9	788.8	70.6	9.5	30.8	56.7
80% piping underground	8.0	277.5	13.4	16.0	1035.0	1838.9	342.9	483.9	827.9	70.6	10.7	32.3	57.4
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
24 Units	3.9	321.1	9.0	18.5	664.2	1503.7	248.3	282.2	531.3	70.6	7.8	20.7	47.0
30 Units	3.7	322.7	9.8	18.6	729.2	1570.8	256.0	326.5	583.3	70.6	8.0	22.8	49.0
Recirc Pump Always On													
Recirc Pump Always On	1.3	335.6	13.3	19.2	1013.9	1868.1	327.3	483.9	811.1	99.7	10.2	31.7	58.3

Figure 14: Climate Zone 12, Building: CT

CZ 12

Building: LR

1334.5978 <-- Ave. area of each appt.
122783 <-- Total Building Area (sf)
2342 <-- Pipe Length (ft.)
92 <-- Number of Appts
0.0191 <-- Pipe Length per sq.ft. (ft.)

CASES	SIMULATION RESULTS												
	Loads in MMbtu of annual energy use						*MMBtu*	*MMBtu*	*MMBtu*	*kWh*	*(KBtu/ ft)*	*(kBtu/sf)*	*(kBtu/sf)*
Case Description	Heating	Cooling	Pumps	Fans	DHW	Total	DHW Pipe Losses	Total Coil Load on Secondary	DHW Heater Energy	Recirc pumps Elec Use	DHW Pipe losses/sf	DHW Loads /sf	Total Loads /sf
Budget BASECASE													
Insulation is 1"													
5% of piping is outdoors (Primary Loop)	6.9	730.7	19.1	35.9	3002.3	5119.7	1167.6	1093.7	2269.7	955.9	9.5	24.5	41.7
Heater is Outdoors													
With Recirc Pump													
Night ShutOff on Recirc Time Control													
Same DWH for washing energy													
% Loop Outdoors													
All piping in Plenum	6.4	733.1	19.0	36.0	2922.5	5041.2	1106.4	1093.7	2204.4	955.9	9.0	23.8	41.1
33% piping outdoors	14.6	648.2	19.3	32.0	3157.0	5202.4	1293.3	1093.7	2396.3	955.9	10.5	25.7	42.4
80% piping outdoors	27.9	551.2	19.4	27.7	3283.3	5247.6	1396.8	1093.7	2499.6	955.9	11.4	26.7	42.7
All piping outdoors	33.7	519.7	19.5	26.4	3367.5	5307.2	1464.6	1093.7	2568.5	955.9	11.9	27.4	43.2
Loop R Value													
Insulation is 1.5" (5% piping outdoors)	8.4	688.9	18.8	33.8	2752.3	4828.8	963.0	1093.7	2065.1	955.9	7.8	22.4	39.3
Insulation is 1.5" (all piping outdoors)	33.7	519.7	19.1	26.4	3039.3	4978.7	1196.2	1093.7	2300.0	955.9	9.7	24.8	40.5
No Recirc Pump													
Recirc Pump removed - 5% piping outdoors	15.8	600.9	15.0	29.7	2220.2	4213.5	539.0	1094.0	1629.8	0.0	4.4	18.1	34.3
Time Control													
Nights & Peak ShutOff 11pm-6am 8am-10am 4pm-6pm	7.8	692.4	18.1	33.9	2818.5	4896.6	1003.7	1093.7	2119.5	730.9	8.2	23.0	39.9
Peak ShutOff 8am-10am 4pm-6pm	2.0	715.7	19.9	34.9	3246.4	5335.6	1365.0	1093.7	2469.5	1124.5	11.1	26.4	43.5
Washing Energy													
Same Water Heater , Separate Loop	7.0	730.4	19.1	35.9	2995.1	5112.4	1163.3	1092.5	2263.8	955.9	9.5	24.4	41.6
Seperate Water Heater , Separate Loop	7.0	730.3	21.1	35.8	3019.9	5139.3	1161.7	1092.5	2198.9	955.9	9.5	24.6	41.9
							Washing loop Heater -->		64.0				
% Loop UnderGround													
5% piping underground	6.7	730.4	19.1	35.8	3006.0	5122.8	1171.2	1093.7	2272.7	955.9	9.5	24.5	41.7
1/3rd piping underground	13.6	647.0	19.3	31.9	3187.6	5230.1	1319.3	1093.7	2421.3	955.9	10.7	26.0	42.6
80% piping underground	27.2	550.6	19.5	27.7	3344.0	5306.6	1447.5	1093.7	2549.3	955.9	11.8	27.2	43.2
Temp Control													
Pump Shutoff													
Water heater output control													
Time / Temp Control													
Demand based controls													
Changed No.of Units													
109 nits	6.7	731.2	19.2	35.9	3104.5	5222.2	1173.1	1172.2	2353.3	955.9	9.6	25.3	42.5
176 Units	5.9	734.1	19.9	36.0	3703.9	5823.0	1207.7	1626.3	2843.7	955.9	9.8	30.2	47.4
Recirc Pump Always On													
Recirc Pump Always On	1.8	753.9	20.9	36.8	3430.6	5560.4	1528.7	1093.7	2620.1	1349.4	12.5	27.9	45.3

Figure 15: Climate Zone 12, Building: LR

Appendix B. Graphs of Results From Parametric Runs

In the following graphs “pipe losses” is just that portion of the DHW load that is associated with distribution system losses. DHW Loads is **total** DHW loads, and “Total Loads” is the combination all building loads (including HVAC).

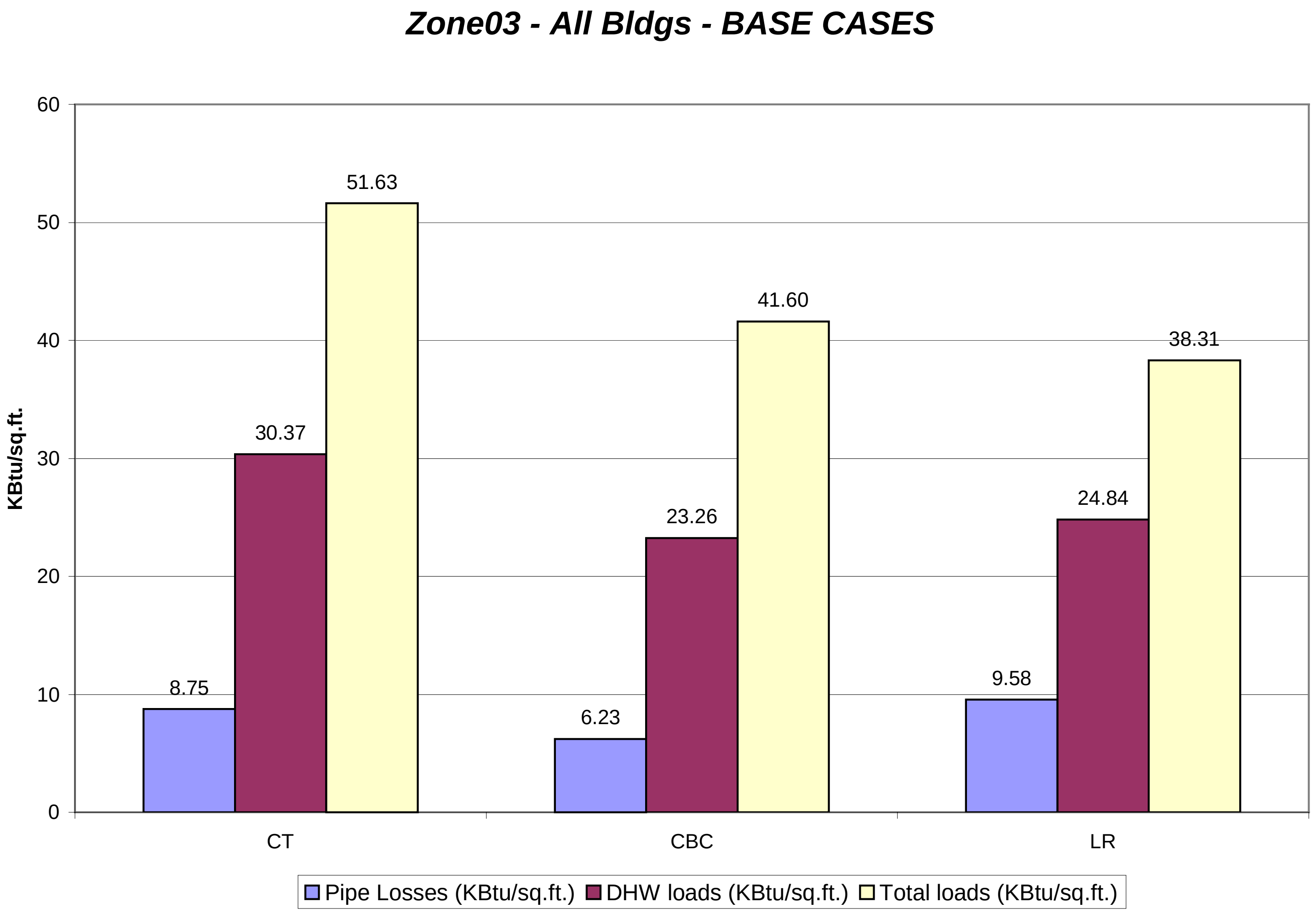

Figure 16: Climate Zone 3-Base Cases- All Buildings

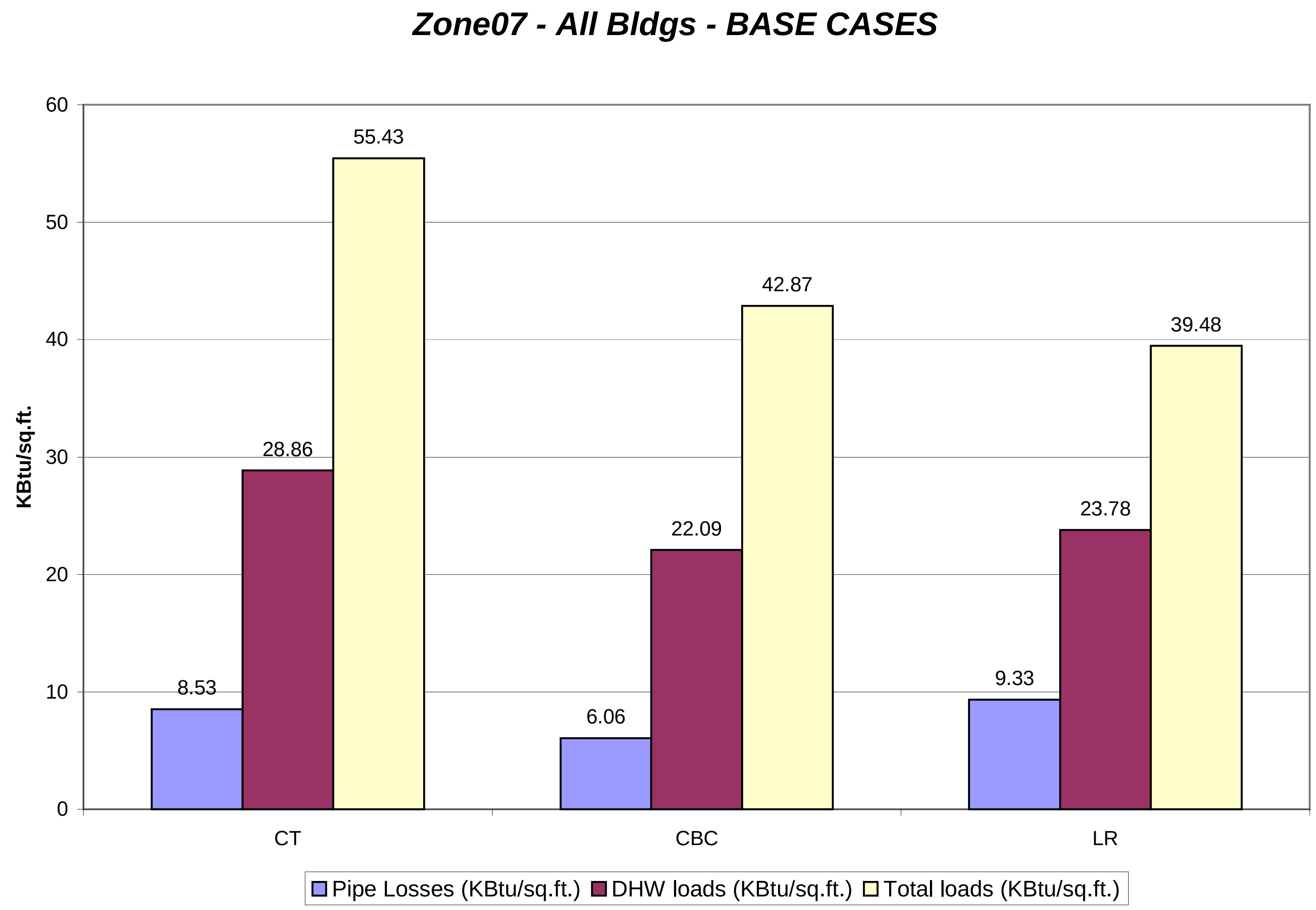

Figure 17: Climate Zone 7- Base cases-All Buildings

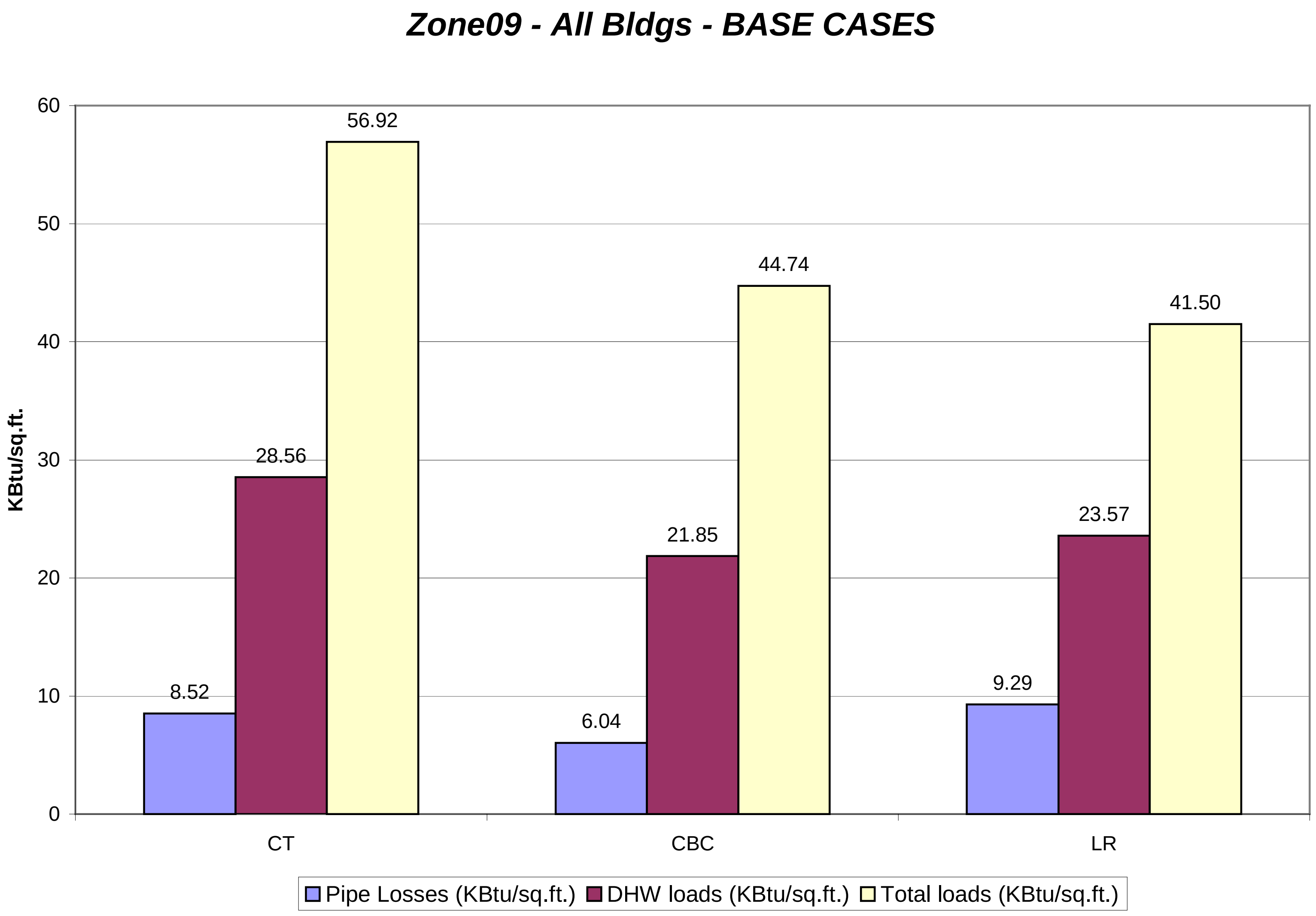

Figure 18: Climate Zone 9-Base Cases-All Buildings

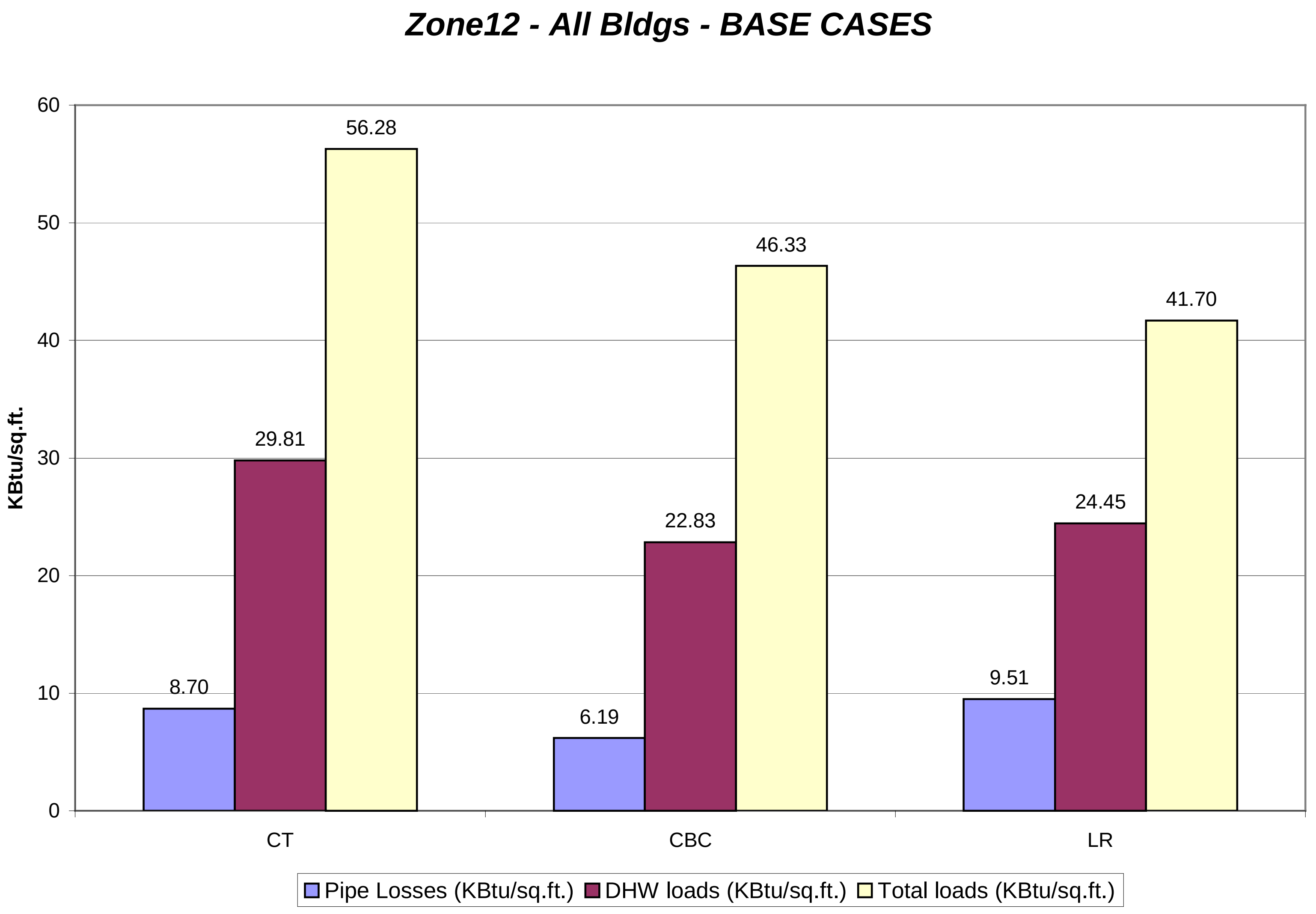

Figure 19: Climate Zone 12- Base Cases-All Buildings

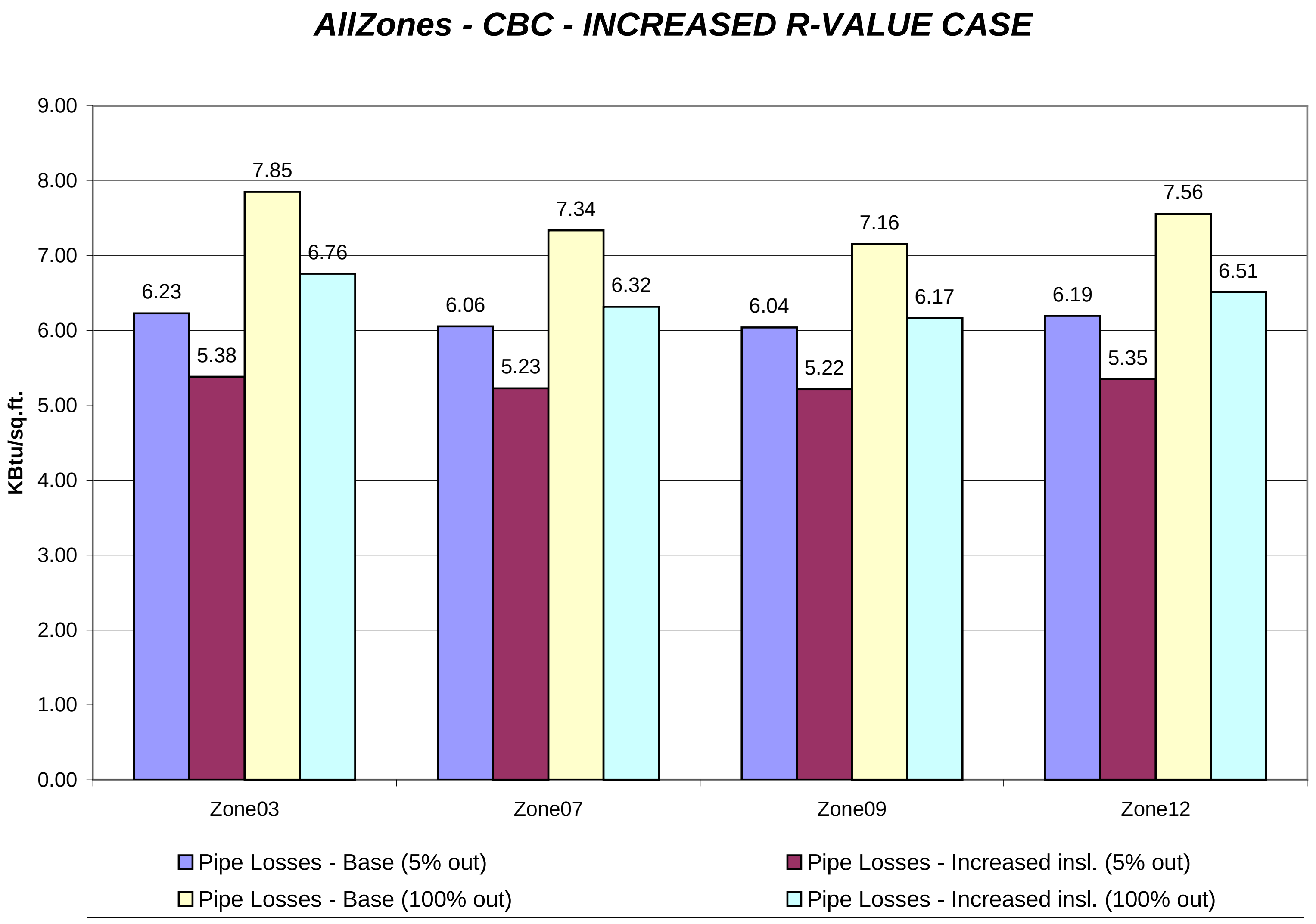

Figure 20: All Zones-CBC- Increased R-Value Case

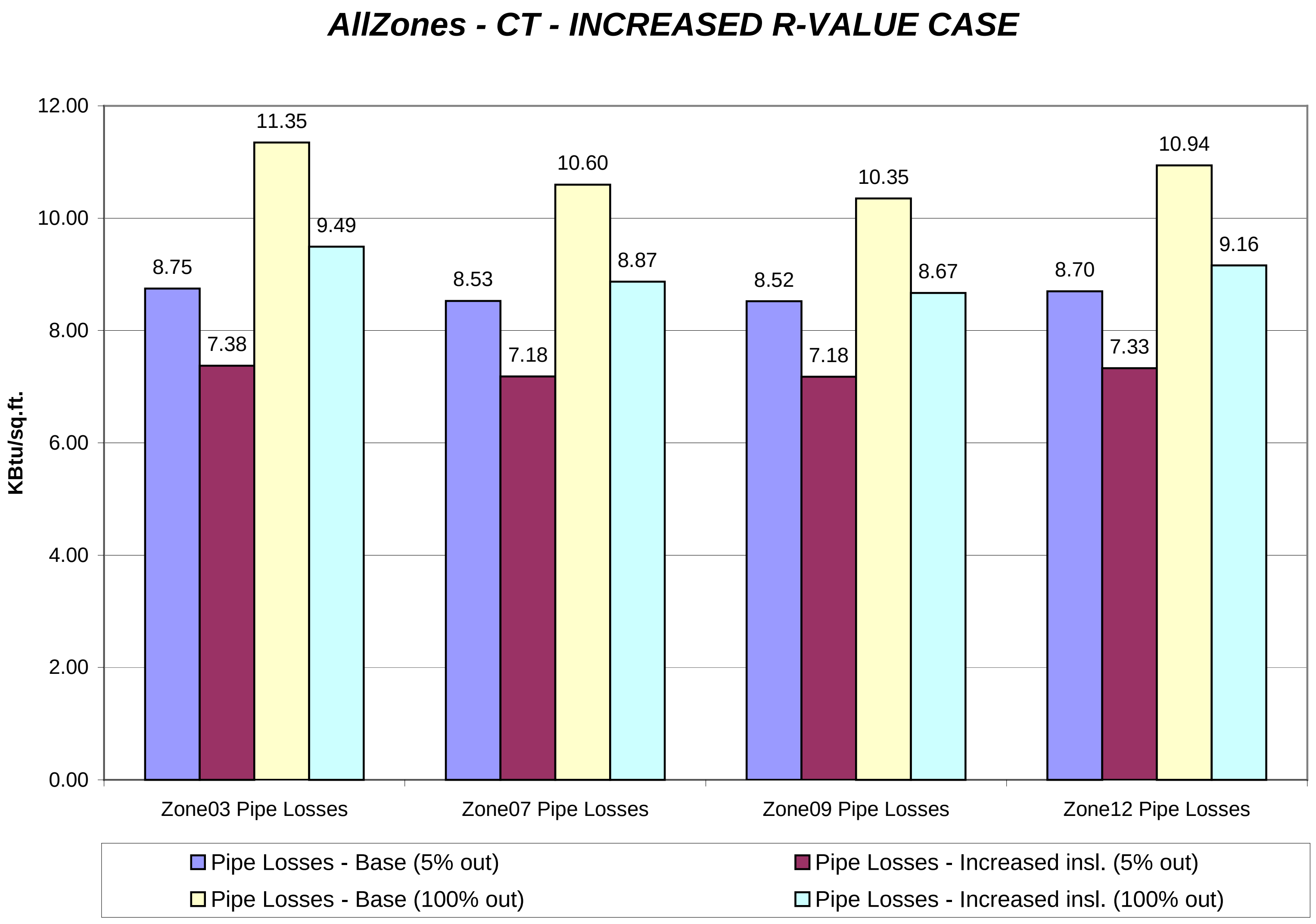

Figure 21: All Zones- CT- Increased R-value

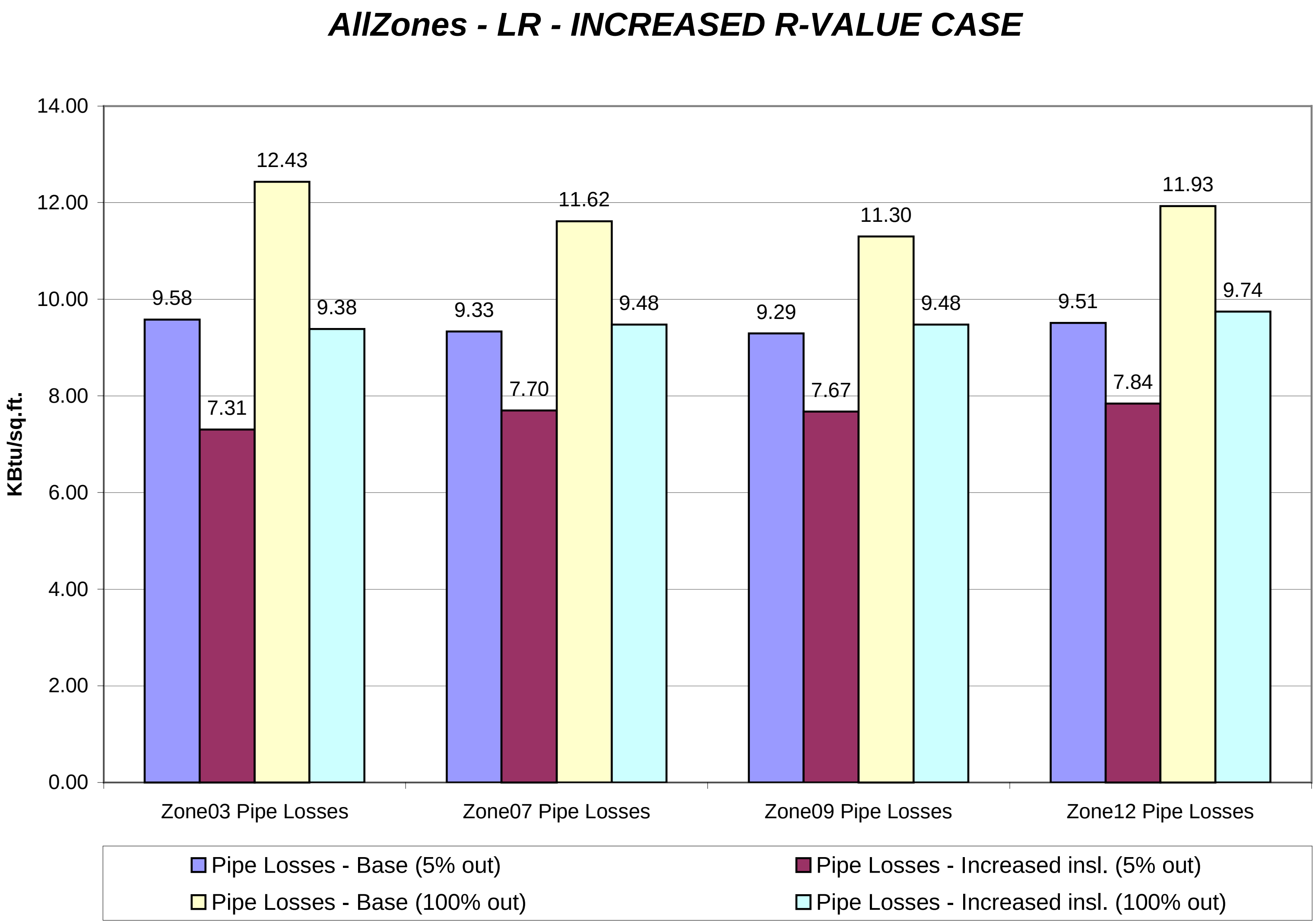

Figure 22: All Zones- LR-Increased R-value Case

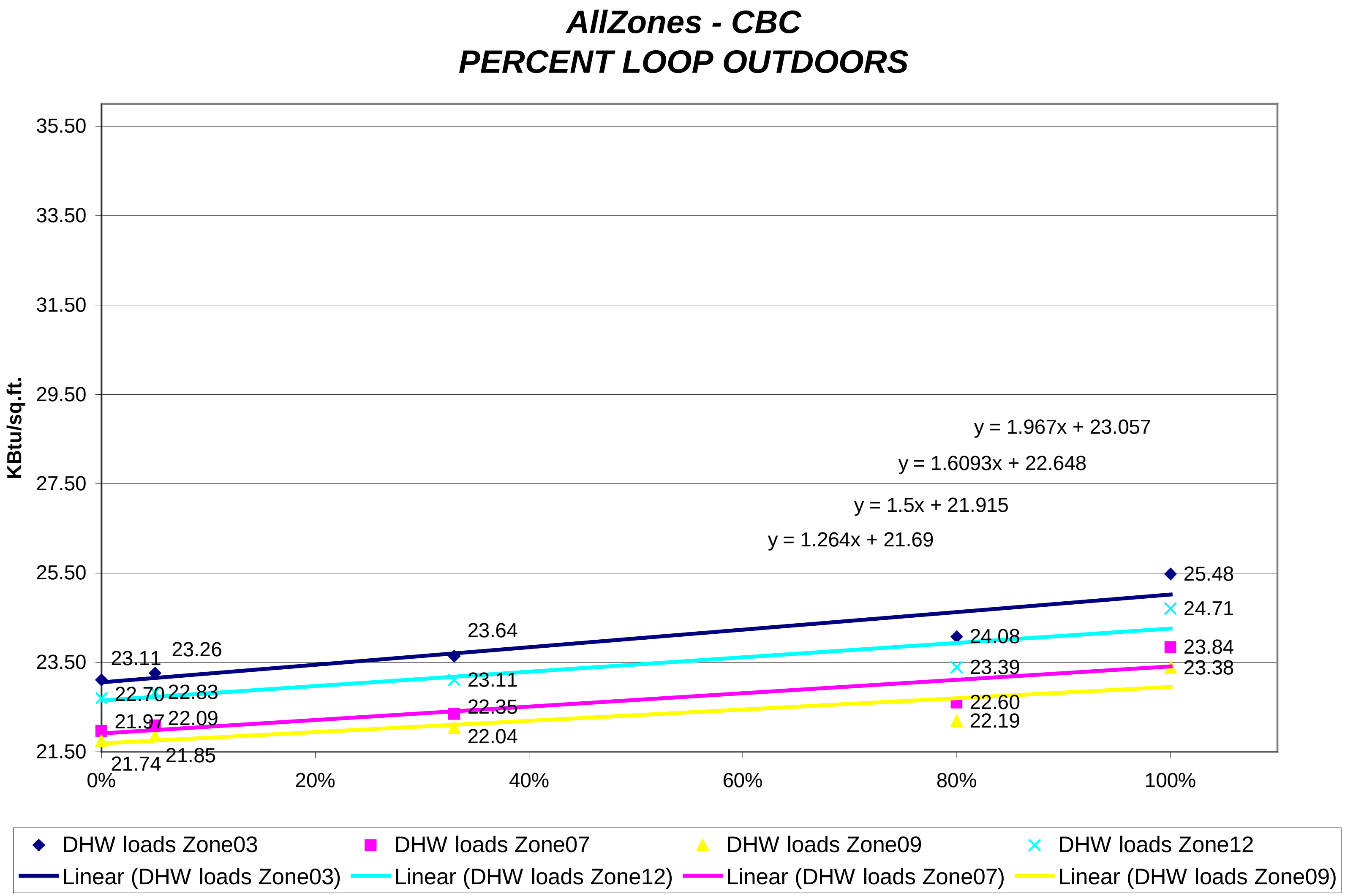

Figure 23: All Zones-CBC-Percent Loop Outdoors (Length of DHW loop pipe-1100sqft, length of pipe/sqft=0.0120sqft)

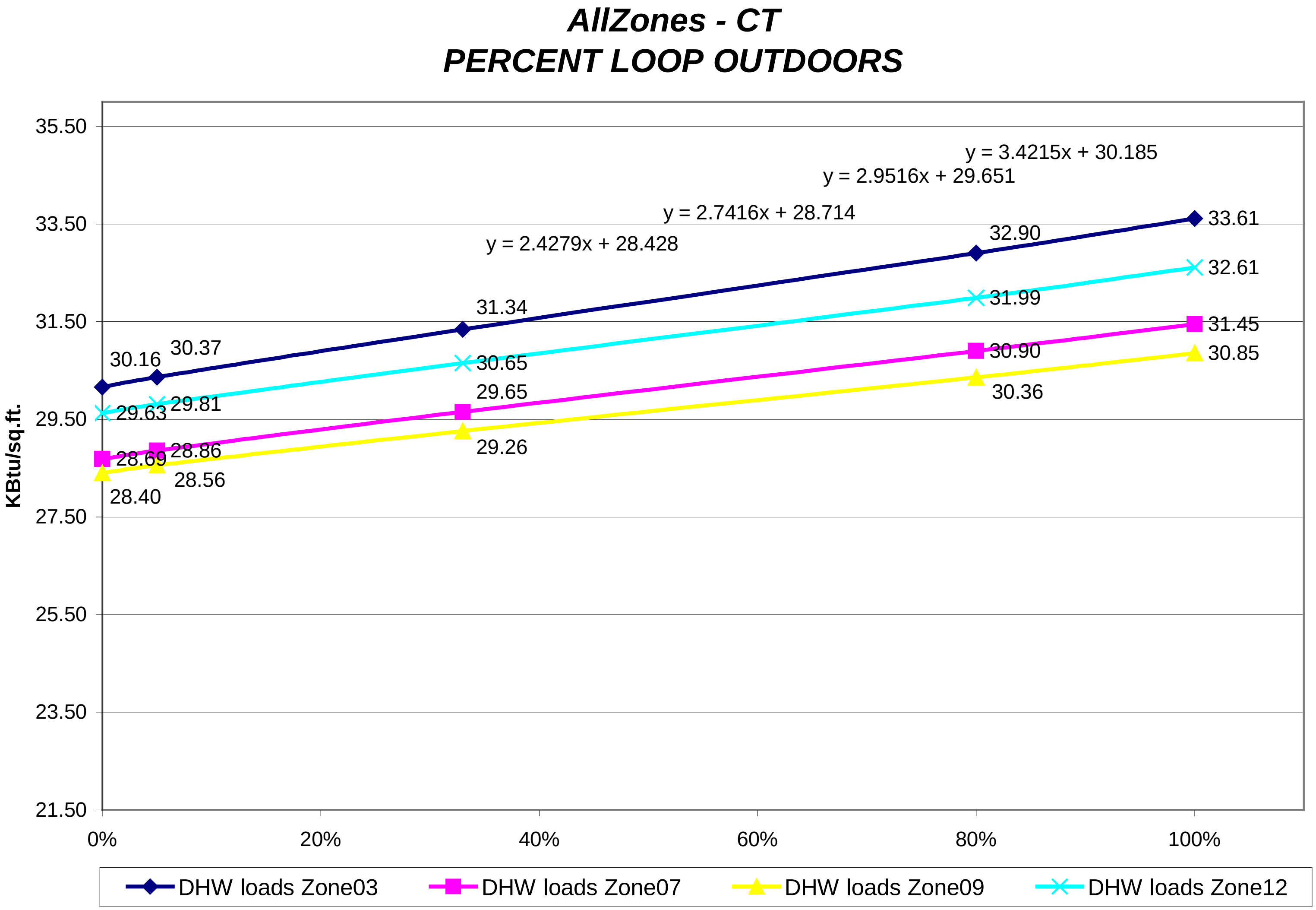

Figure 24: All Zones-CT -Percent Loop Outdoors (Length of DHW loop pipe-538sqft, length of pipe/sqft=0.0168sqft)

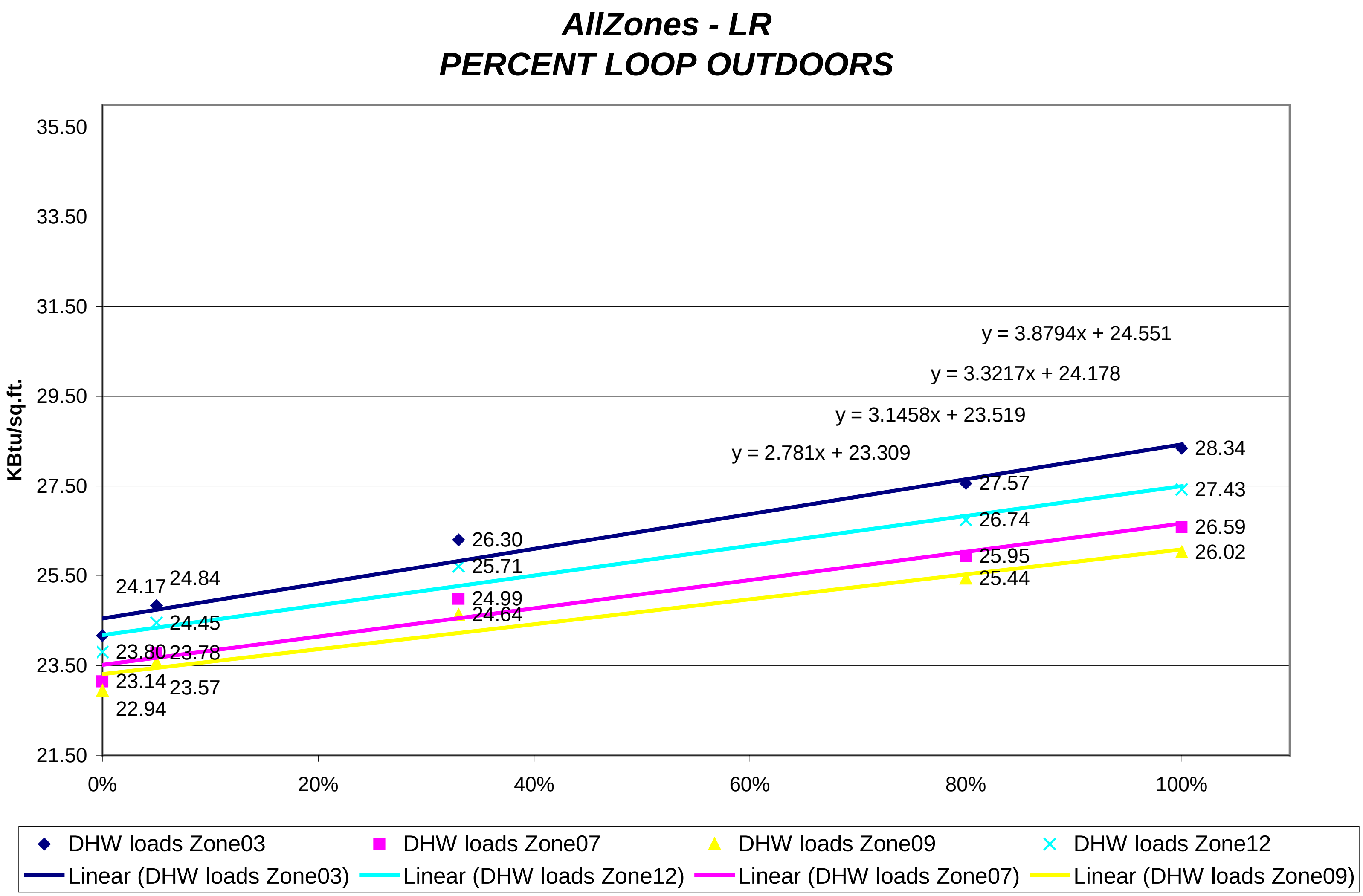

Figure 25: All Zones-LR-Percent Loop Outdoors (Length of DHW loop pipe-2342sqft, length of pipe/sqft=0.0191sqft)

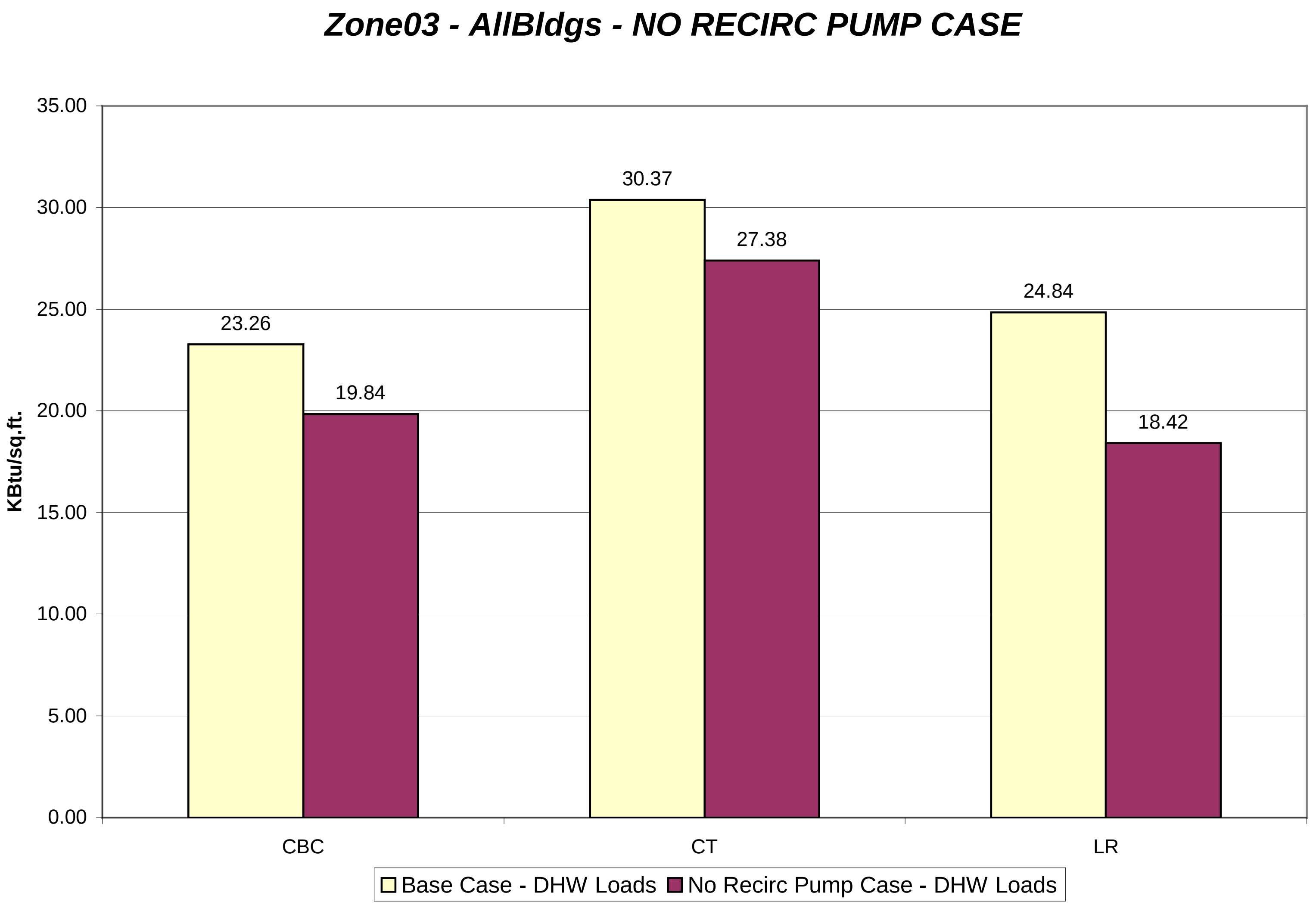

Figure 26: Climate Zone 3- All Buildings-No Recirc Pump Case

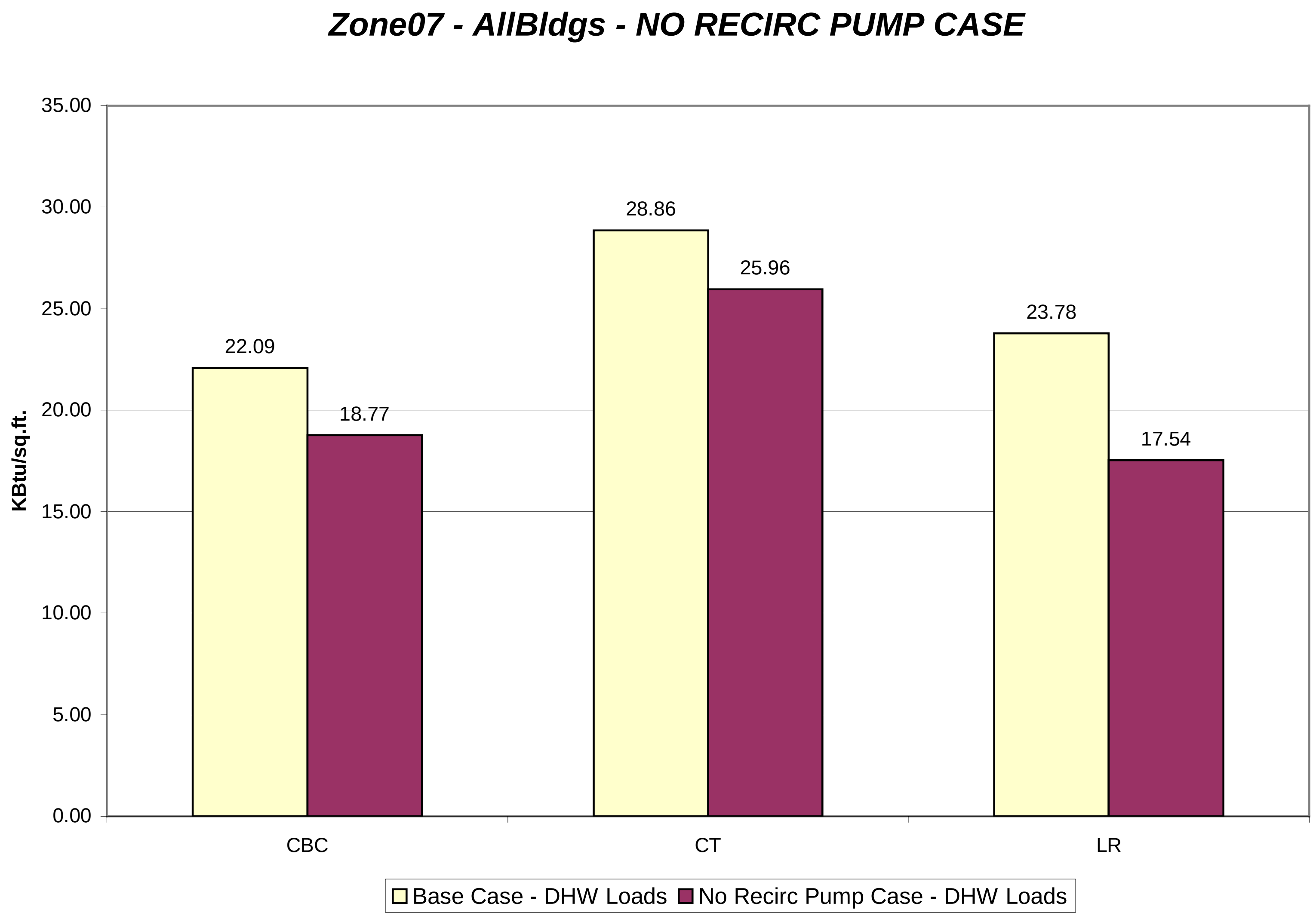

Figure 27: Climate Zone 7- All Buildings- No Recirc Pump Case

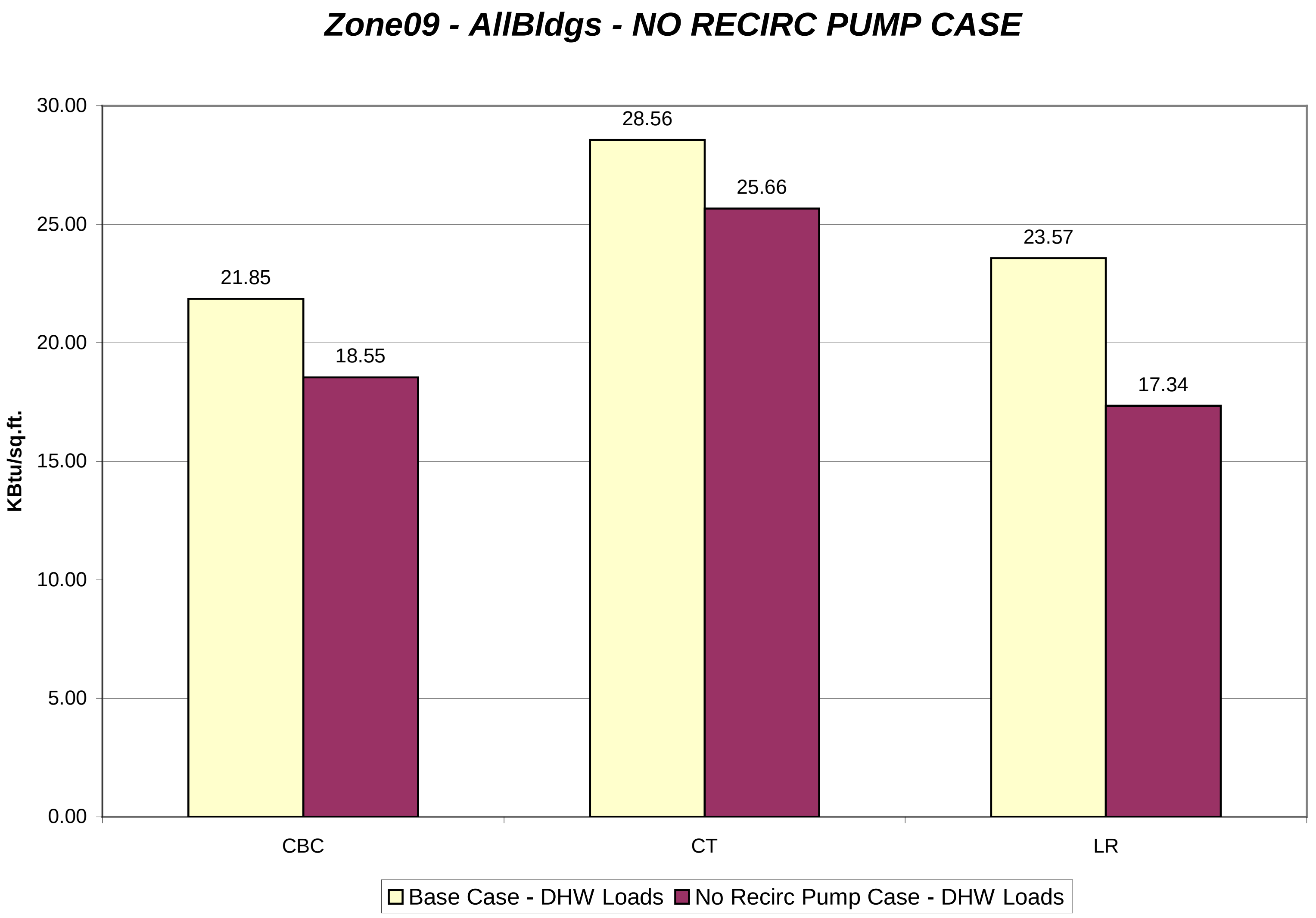

Figure 28: Climate Zone 9 - All Buildings- No Recirc Pump Case

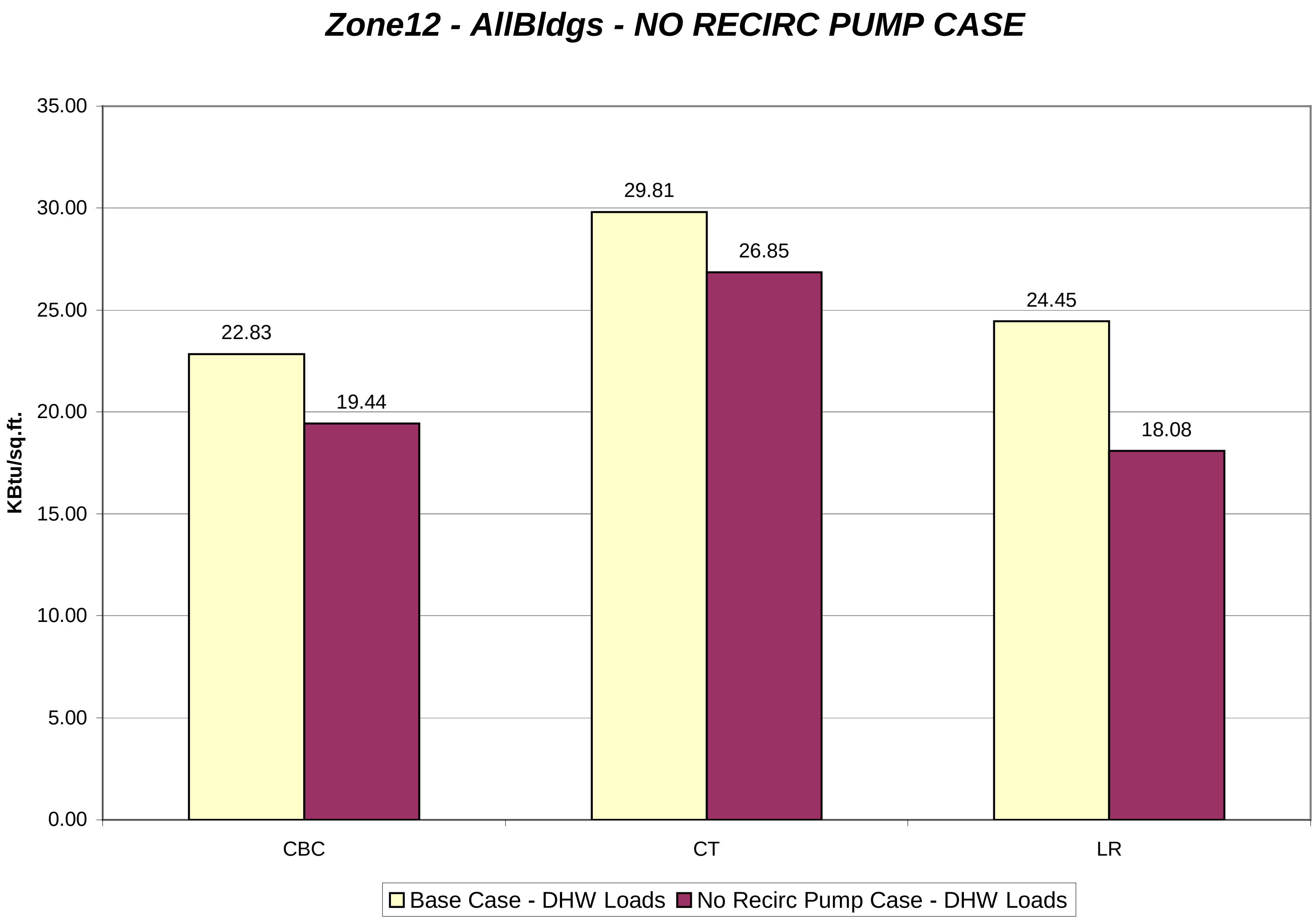

Figure 29: Climate Zone 12 - All Buildings- No Recirc Pump Case

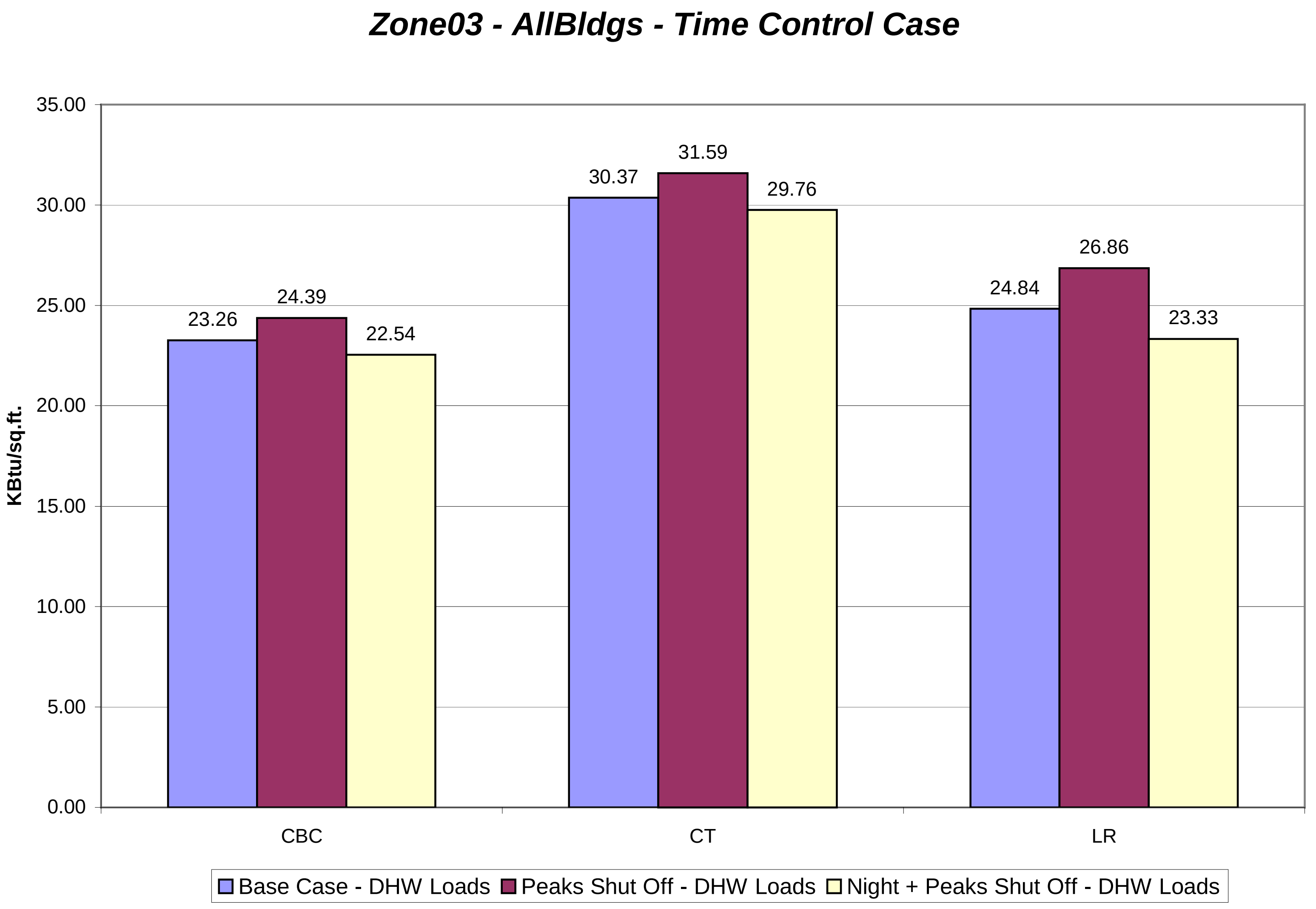

Figure 30: Climate Zone 3: All Buildings- Time Control Case

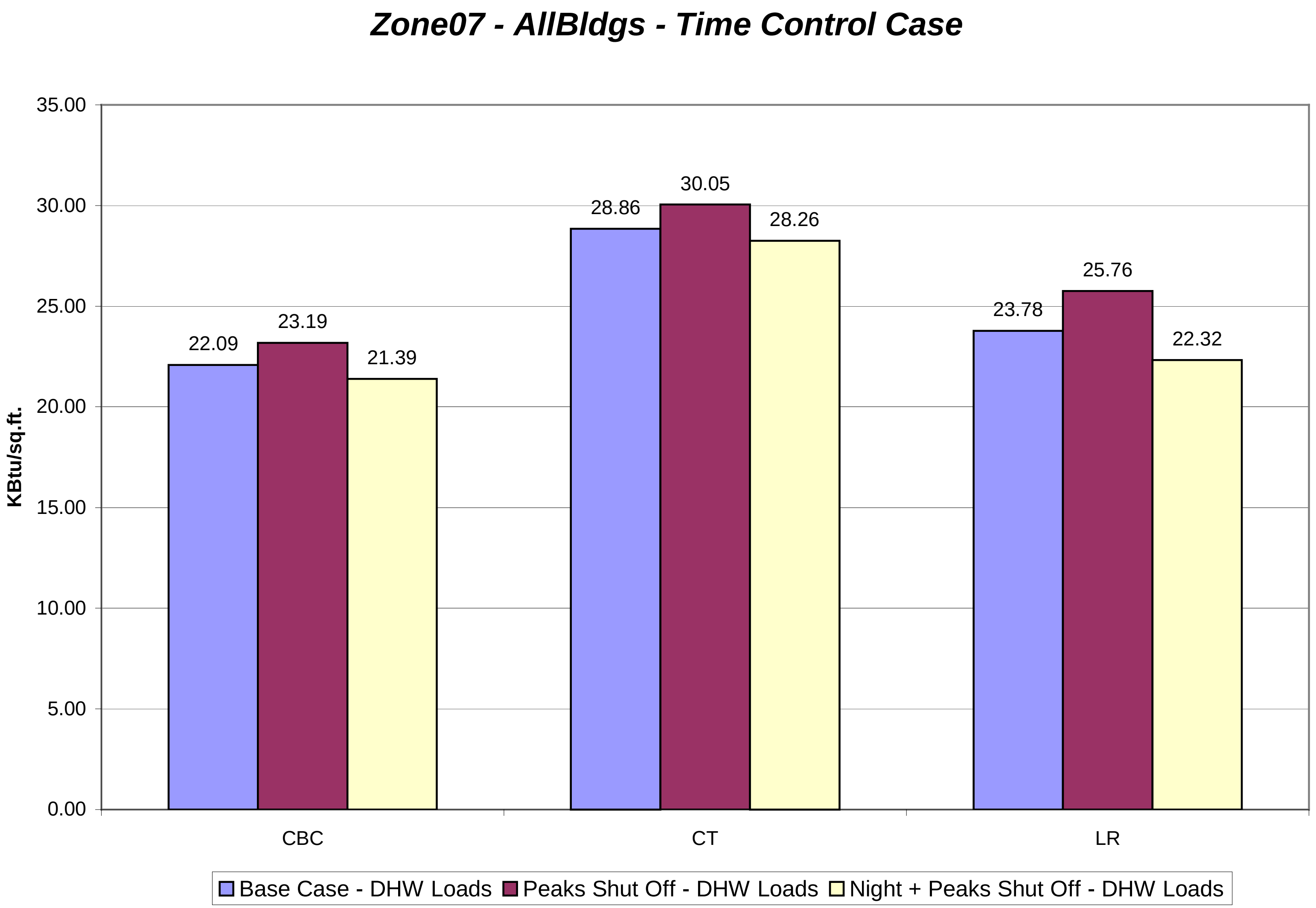

Figure 31: Climate Zone 7: All Buildings- Time Control Case

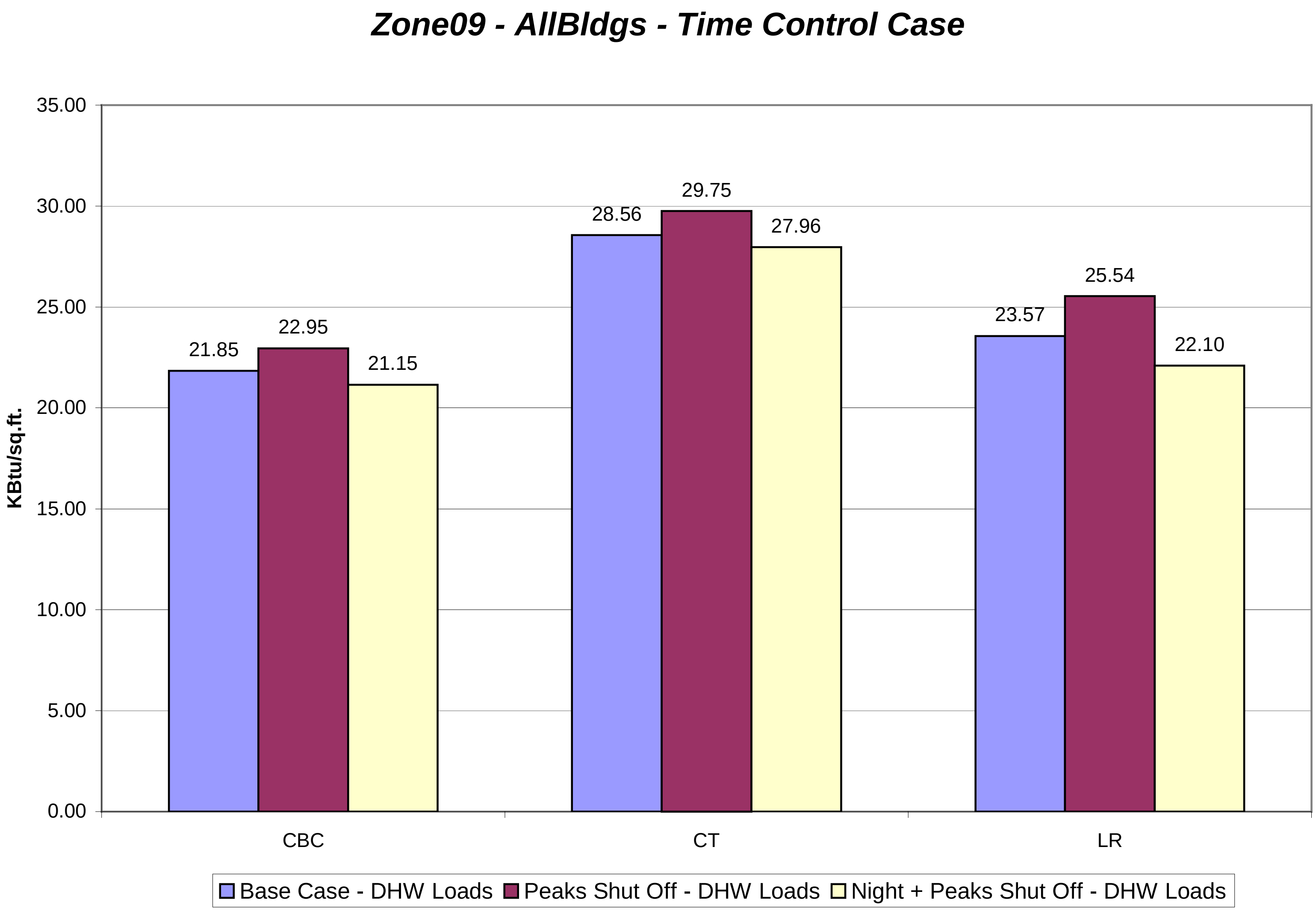

Figure 32: Climate Zone 9: All Buildings- Time Control Case

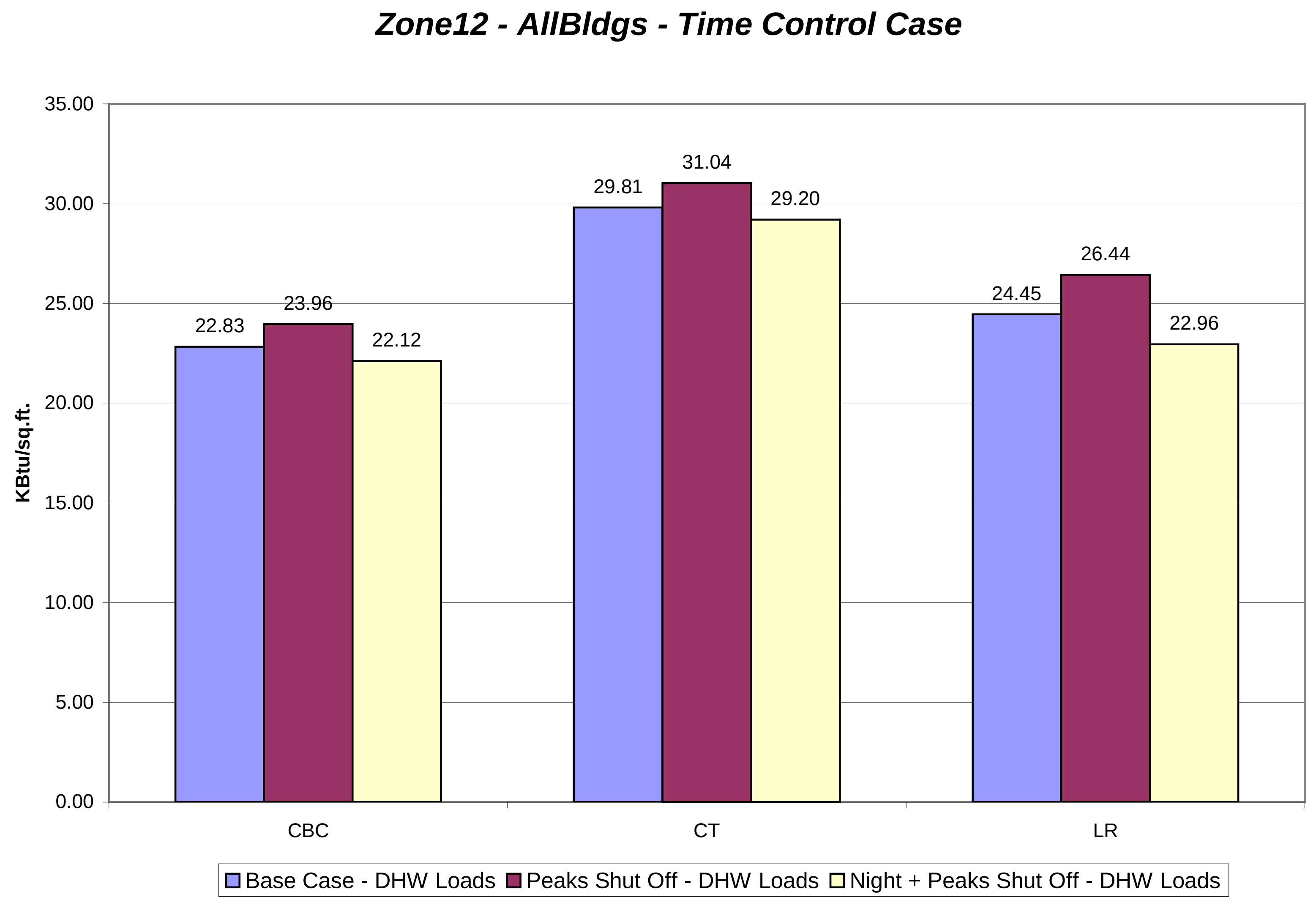

Figure 33: Climate Zone 12: All Buildings- Time Control Case

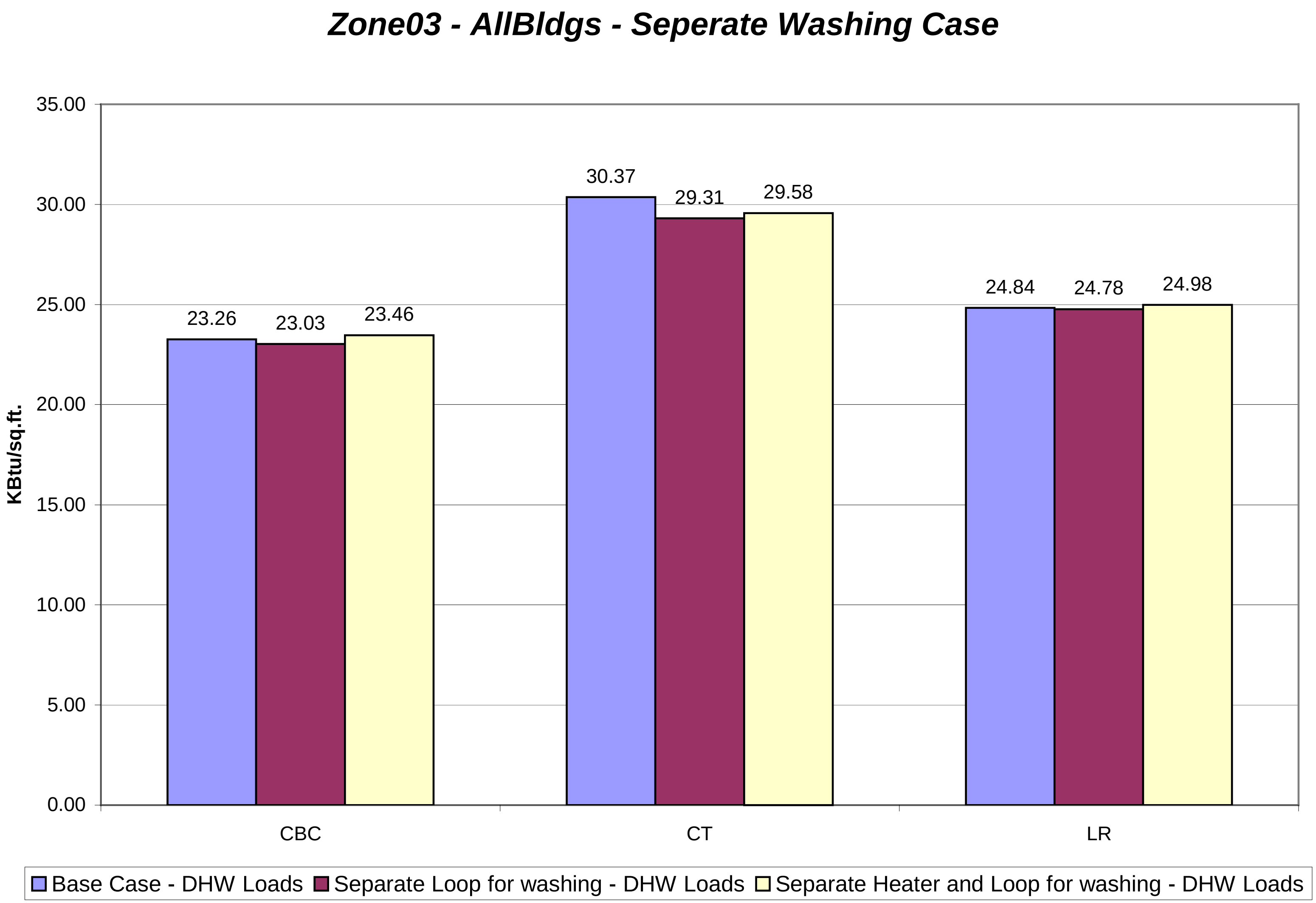

Figure 34: Climate Zone 3: All Buildings- Separate Washing Case

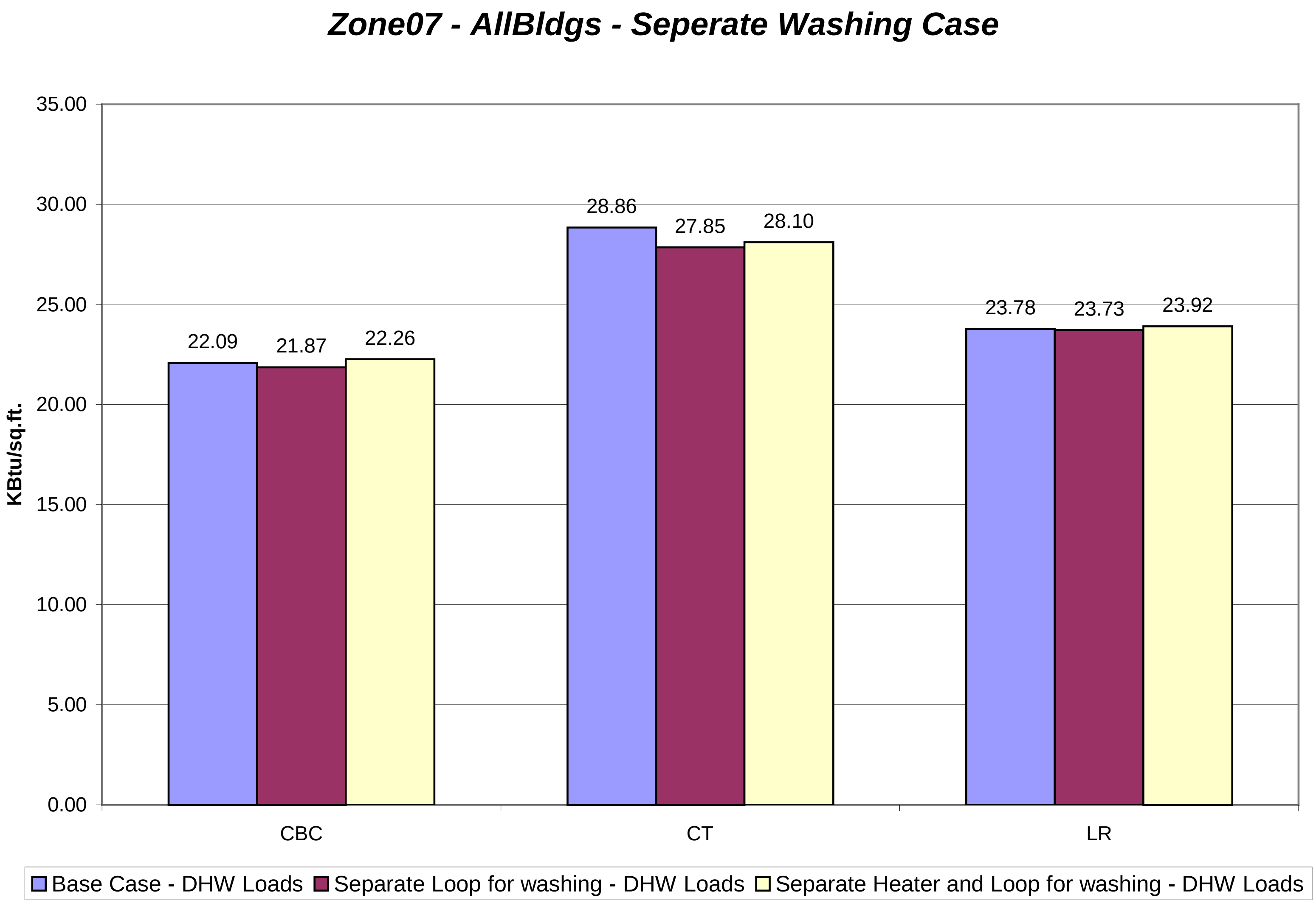

Figure 35: Climate Zone 7: All Buildings- Separate Washing Case

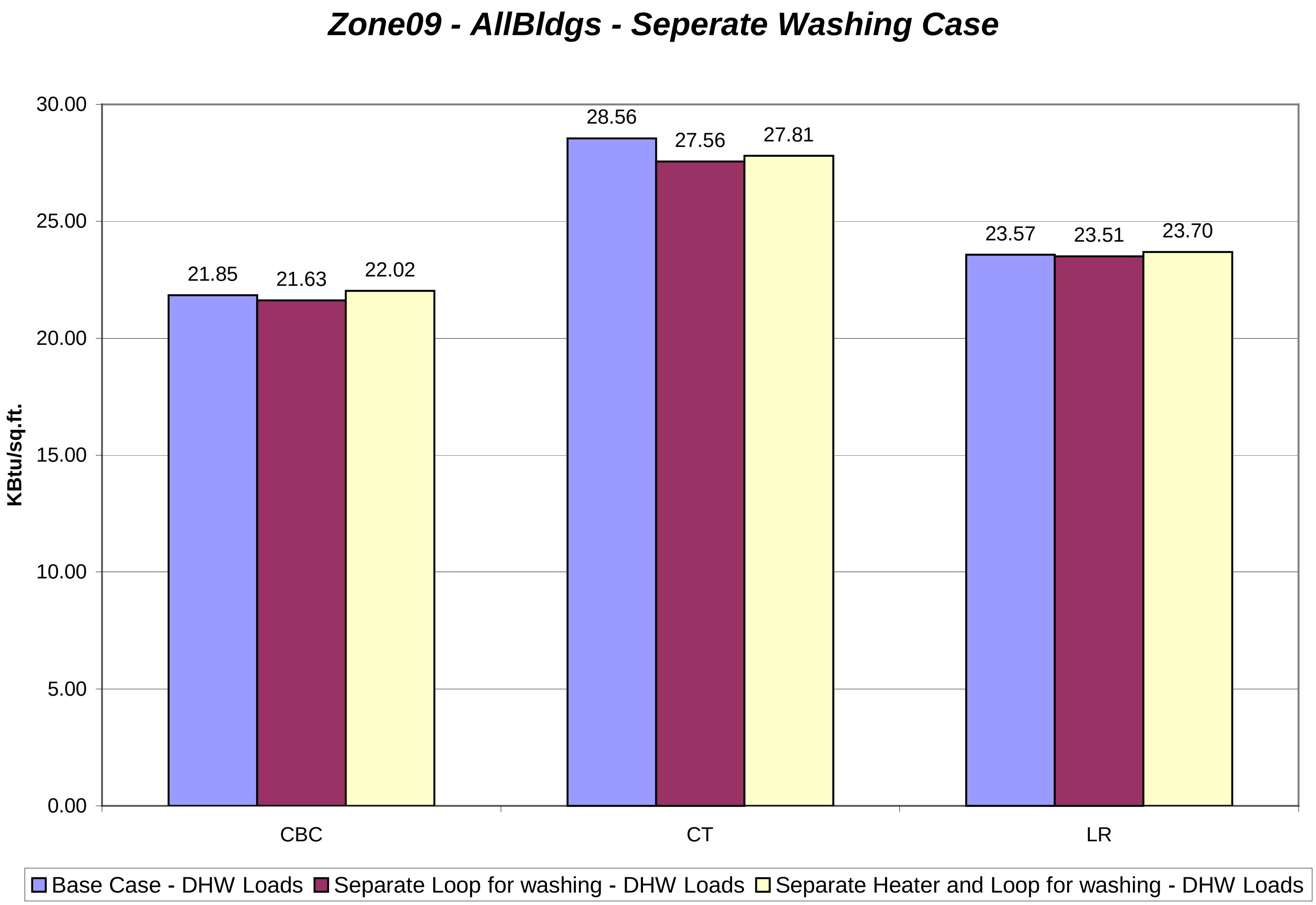

Figure 36: Climate Zone 9: All Buildings- Separate Washing Case

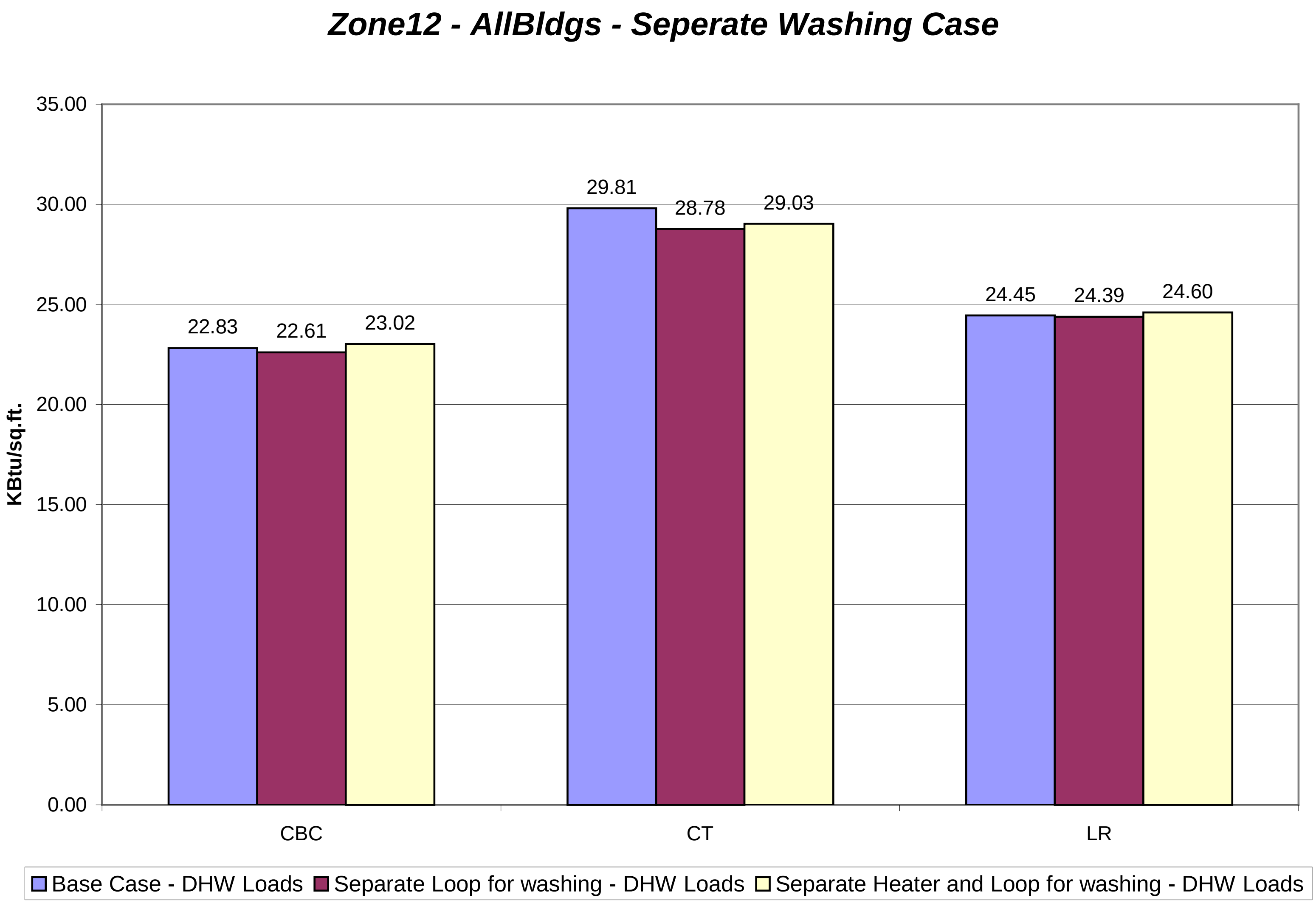

Figure 37: Climate Zone 12: All Buildings- Separate Washing Case

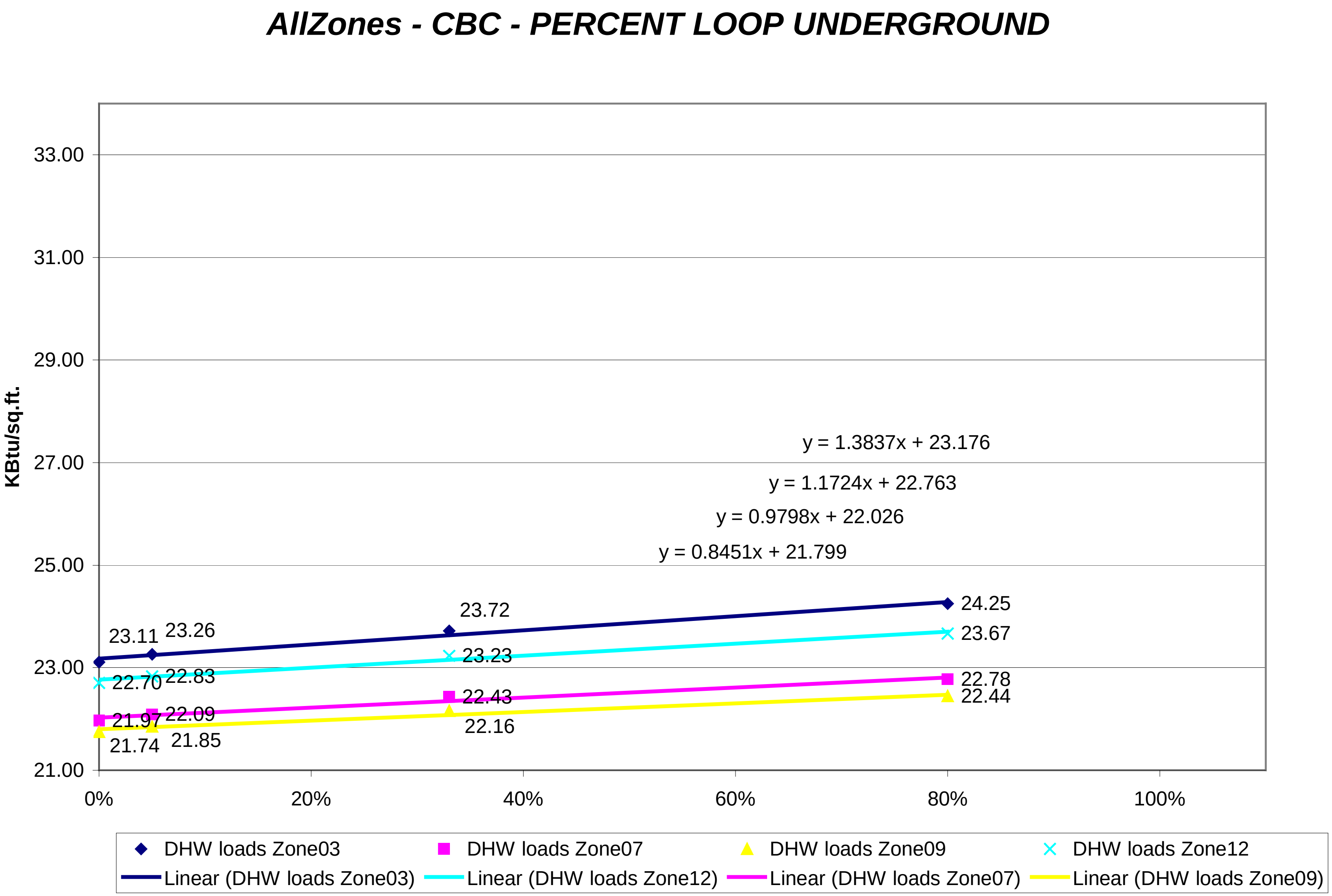

Figure 38: All Zones-CBC-Percent Loop Underground

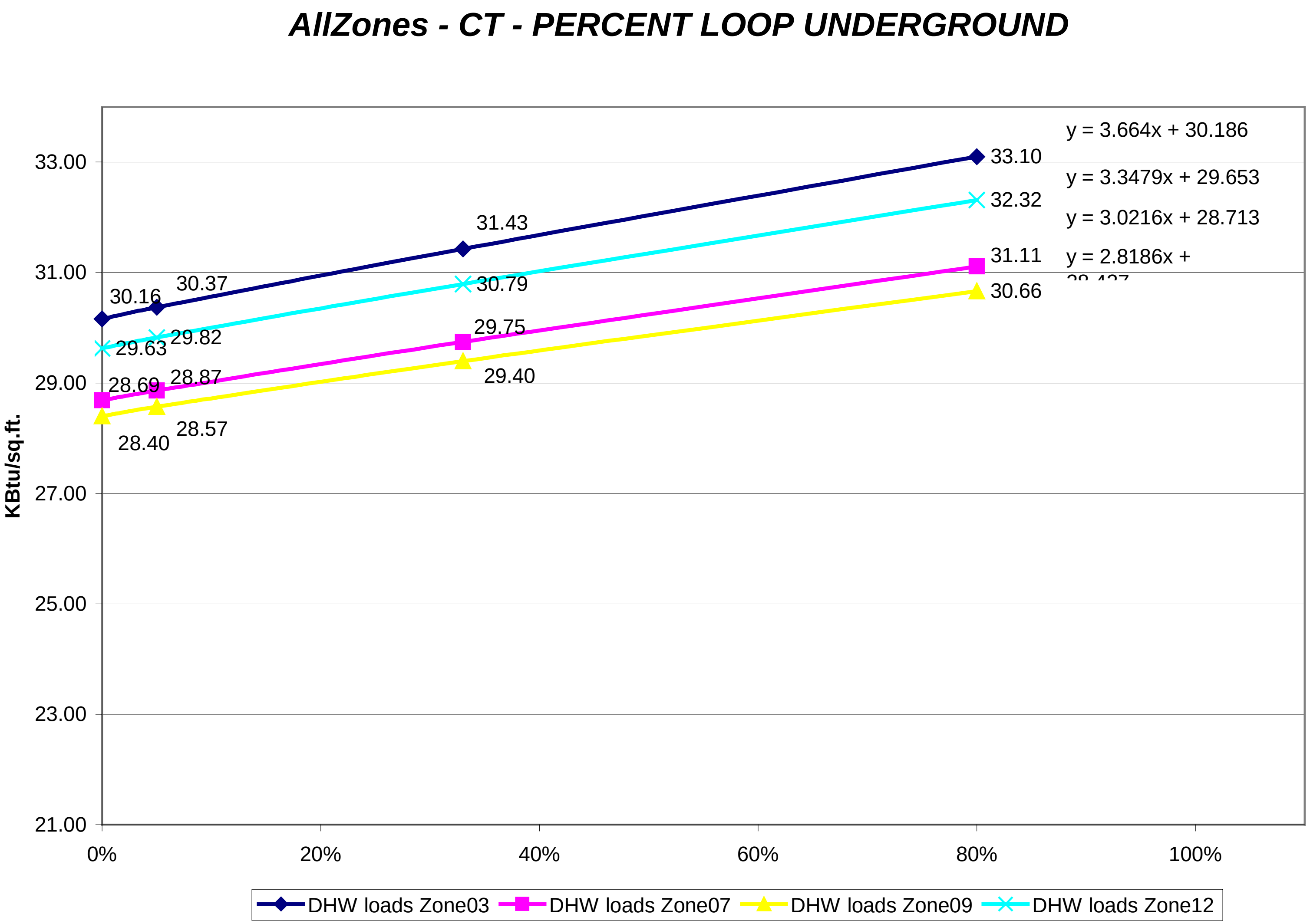

Figure 39: All Zones-CT -Percent Loop Underground

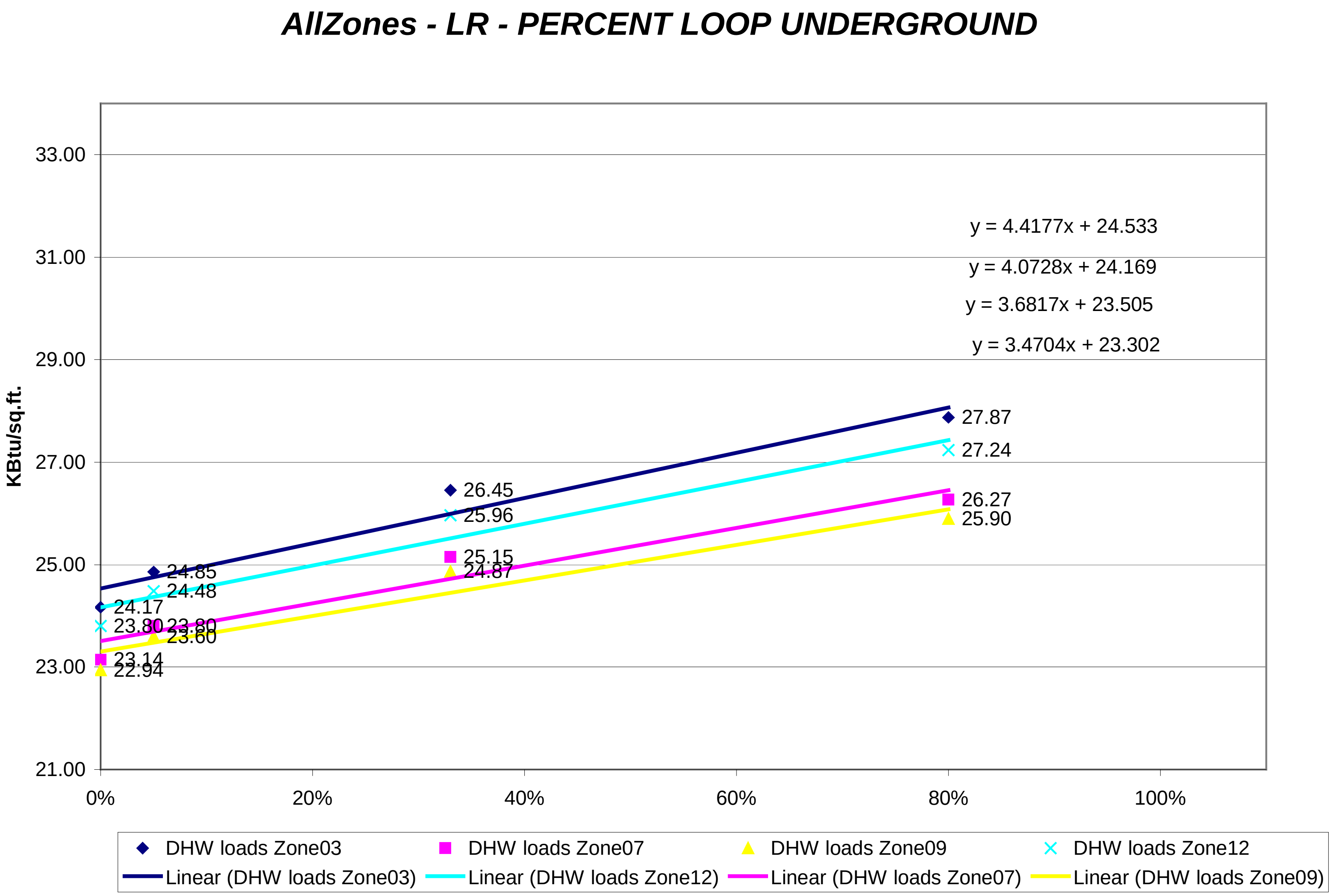

Figure 40: All Zones-LR -Percent Loop Underground

Appendix C. Summary of Results from Parametric Runs

In these charts, Pipe losses (kBtu/yr-sq.ft.) and Total DHW Loads (kBtu/yr-sq.ft.) from selected eight parametric runs are compared to the base case run for each building and climate zone. A delta between the base case and the parametric runs is taken and percent change is calculated.

	Pipe Losses (kBtu/sq.ft.)	*Total DHW (kBtu/sq.ft.)*	*DELTA from BASECASE*	*Percent*
CBC - CZ03				
Base Case	6.23	23.26	N/A	N/A
No Recirc Pumps	3.77	19.84	3.42	14.71%
Recirc Pump, No controls	7.64	25.13	-1.87	-8.05%
80% of Pipe Outside	6.82	24.08	-0.82	-3.52%
Increased R-value	5.38	22.10	1.16	4.99%
5% of Pipe Underground	6.23	23.26	0.00	0.00%
80% of Pipe Ungerground	6.95	24.25	*-0.17*	*-0.70%*
Separate washing Loop	6.07	23.03	0.23	0.97%
Separate washing Heater and Loop	6.05	23.46	-0.20	-0.87%
CBC - CZ07				
Base Case	6.06	22.09	N/A	N/A
No Recirc Pumps	3.67	18.77	3.32	15.02%
Recirc Pump, No controls	7.43	23.92	-1.83	-8.28%
80% of Pipe Outside	6.42	22.60	-0.51	-2.31%
Increased R-value	5.23	20.96	1.13	5.11%
5% of Pipe Underground	6.06	22.09	0.00	0.00%
80% of Pipe Ungerground	6.56	22.78	*-0.18*	*-0.78%*
Separate washing Loop	5.90	21.87	0.22	1.00%
Separate washing Heater and Loop	5.88	22.26	-0.18	-0.80%
CBC - CZ09				
Base Case	6.04	21.85	N/A	N/A
No Recirc Pumps	3.67	18.55	3.30	15.12%
Recirc Pump, No controls	7.41	23.68	-1.83	-8.37%
80% of Pipe Outside	6.28	22.19	-0.34	-1.55%
Increased R-value	5.22	20.72	1.13	5.16%
5% of Pipe Underground	6.04	21.85	0.00	0.00%
80% of Pipe Ungerground	6.47	22.44	*-0.25*	*-1.14%*
Separate washing Loop	5.88	21.63	0.22	1.01%
Separate washing Heater and Loop	5.87	22.02	-0.17	-0.78%
CBC - CZ12				
Base Case	6.19	22.83	N/A	N/A
No Recirc Pumps	3.75	19.44	3.39	14.86%
Recirc Pump, No controls	7.60	24.71	-1.87	-8.20%
80% of Pipe Outside	6.60	23.39	-0.56	-2.45%
Increased R-value	5.35	21.68	1.15	5.05%
5% of Pipe Underground	6.19	22.83	0.00	0.00%
80% of Pipe Ungerground	6.80	23.67	*-0.27*	*-1.17%*
Separate washing Loop	6.03	22.61	0.23	0.99%
Separate washing Heater and Loop	6.02	23.02	-0.19	-0.83%

Figure 41: Summary Results- Building: CBC

	Pipe Losses (kBtu/sq.ft.)	***Total DHW (kBtu/sq.ft.)***	***DELTA from BASECASE***	***Percent***
CT - CZ03				
Base Case	8.75	30.37	N/A	N/A
No Recirc Pumps	6.40	27.38	2.98	9.82%
Recirc Pump, No controls	10.27	32.21	-1.85	-6.09%
80% of Pipe Outside	10.78	32.90	-2.54	-8.36%
Increased R-value	7.38	28.65	1.72	5.66%
5% of Pipe Underground	8.76	30.37	-0.01	-0.03%
80% of Pipe Ungerground	10.94	33.10	*-0.20*	*-0.61%*
Separate washing Loop	8.49	29.31	1.06	3.48%
Separate washing Heater and Loop	8.45	29.58	0.79	2.60%
CT - CZ07				
Base Case	8.53	28.86	N/A	N/A
No Recirc Pumps	6.24	25.96	2.90	10.05%
Recirc Pump, No controls	10.01	30.66	-1.81	-6.26%
80% of Pipe Outside	10.16	30.90	-2.04	-7.08%
Increased R-value	7.18	27.18	1.68	5.81%
5% of Pipe Underground	8.54	28.87	-0.01	-0.03%
80% of Pipe Ungerground	10.34	31.11	*-0.22*	*-0.70%*
Separate washing Loop	8.27	27.85	1.00	3.47%
Separate washing Heater and Loop	8.24	28.10	0.75	2.61%
CT - CZ09				
Base Case	8.52	28.56	N/A	N/A
No Recirc Pumps	6.24	25.66	2.89	10.14%
Recirc Pump, No controls	10.00	30.37	-1.81	-6.33%
80% of Pipe Outside	9.96	30.36	-1.80	-6.32%
Increased R-value	7.18	26.88	1.68	5.87%
5% of Pipe Underground	8.53	28.57	-0.01	-0.04%
80% of Pipe Ungerground	10.20	30.66	*-0.30*	*-1.00%*
Separate washing Loop	8.26	27.56	0.99	3.48%
Separate washing Heater and Loop	8.22	27.81	0.75	2.62%
CT - CZ12				
Base Case	8.70	29.81	N/A	N/A
No Recirc Pumps	6.37	26.85	2.96	9.94%
Recirc Pump, No controls	10.22	31.66	-1.85	-6.20%
80% of Pipe Outside	10.44	31.99	-2.18	-7.32%
Increased R-value	7.33	28.10	1.71	5.73%
5% of Pipe Underground	8.72	29.82	-0.02	-0.05%
80% of Pipe Ungerground	10.71	32.32	*-0.32*	*-1.02%*
Separate washing Loop	8.44	28.78	1.03	3.47%
Separate washing Heater and Loop	8.41	29.03	0.78	2.61%

Figure 42: Summary Sheet- Building: CT

	Pipe Losses (kBtu/sq.ft.)	Total DHW (kBtu/sq.ft.)	DELTA from BASECASE	Percent
LR - CZ03				
Base Case	9.58	24.84	N/A	N/A
No Recirc Pumps	4.41	18.42	6.42	25.84%
Recirc Pump, No controls	4.41	18.42	6.42	25.84%
80% of Pipe Outside	11.81	27.57	-2.73	-10.99%
Increased R-value	7.31	22.79	2.05	8.25%
5% of Pipe Underground	9.59	24.85	-0.02	-0.07%
80% of Pipe Ungerground	12.06	27.87	*-0.31*	*-1.11%*
Separate washing Loop	9.54	24.78	0.06	0.24%
Separate washing Heater and Loop	9.53	24.98	-0.15	-0.59%
LR - CZ07				
Base Case	9.33	23.78	N/A	N/A
No Recirc Pumps	1.41	17.54	6.25	26.26%
Recirc Pump, No controls	1.41	17.54	6.25	26.26%
80% of Pipe Outside	11.10	25.95	-2.16	-9.09%
Increased R-value	7.70	21.79	2.00	8.40%
5% of Pipe Underground	9.35	23.80	-0.02	-0.08%
80% of Pipe Ungerground	11.36	26.27	*-0.32*	*-1.23%*
Separate washing Loop	9.30	23.73	0.06	0.25%
Separate washing Heater and Loop	9.28	23.92	-0.14	-0.57%
LR - CZ09				
Base Case	9.29	23.57	N/A	N/A
No Recirc Pumps	4.28	17.34	6.23	26.42%
Recirc Pump, No controls	4.28	17.34	6.23	26.42%
80% of Pipe Outside	10.82	25.44	-1.87	-7.94%
Increased R-value	7.67	21.58	1.99	8.45%
5% of Pipe Underground	9.33	23.60	-0.03	-0.12%
80% of Pipe Ungerground	11.20	25.90	*-0.46*	*-1.80%*
Separate washing Loop	9.26	23.51	0.06	0.25%
Separate washing Heater and Loop	9.25	23.70	-0.13	-0.56%
LR - CZ12				
Base Case	9.51	24.45	N/A	N/A
No Recirc Pumps	4.39	18.08	6.37	26.05%
Recirc Pump, No controls	4.39	18.08	6.37	26.05%
80% of Pipe Outside	11.38	26.74	-2.29	-9.36%
Increased R-value	7.84	22.42	2.04	8.33%
5% of Pipe Underground	9.54	24.48	-0.03	-0.12%
80% of Pipe Ungerground	11.79	27.24	*-0.49*	*-1.85%*
Separate washing Loop	9.47	24.39	0.06	0.24%
Separate washing Heater and Loop	9.46	24.60	-0.14	-0.59%

Figure 43: Summary Sheet- Building: LR

Appendix D. Hourly Domestic Hot Water Load Calculations

Fractional Schedule from HWSIM runs from Davis Energy Group were used to calculate hourly domestic hot water usage for the three buildings analyzed in this study. These charts show the loads provide by DEG, the calculations for maximum flow, and the fractional rate which were used as inputs in the simulation.

Building: CBC

Appt Size (sq.ft)	No. of appts in the building	Daily DHW rec load (gal/day-apt)	Daily BUILDING rec load (gal/day)	Floor Area (sq.ft.)
720	30	36.6	1098	21600
960	35	42.1	1473.5	33600
1200	23	45.5	1046.5	27600
Totals ->	**88**		**3618**	**82800**

Hour	Load Distribution Fraction	Hourly Load on DHW (gallons)	Minute Load on DHW (gallons)	Fractional Rate of Max Draw
1	0.019	69	1.15	**0.10**
2	0.014	52	0.87	**0.08**
3	0.012	43	0.72	**0.06**
4	0.012	44	0.73	**0.06**
5	0.019	67	1.12	**0.10**
6	0.032	117	1.94	**0.17**
7	0.053	191	3.18	**0.28**
8	0.063	228	11.42	**1.00**
9	0.063	227	3.78	**0.33**
10	0.063	228	3.80	**0.33**
11	0.061	222	3.70	**0.32**
12	0.057	205	3.41	**0.30**
13	0.052	188	3.13	**0.27**
14	0.045	164	2.73	**0.24**
15	0.038	138	2.31	**0.20**
16	0.038	139	2.32	**0.20**
17	0.045	162	2.70	**0.24**
18	0.053	190	3.17	**0.28**
19	0.057	207	3.45	**0.30**
20	0.051	186	3.10	**0.27**
21	0.047	171	2.86	**0.25**
22	0.042	152	2.53	**0.22**
23	0.035	125	2.09	**0.18**
24	0.028	102	1.70	**0.15**
	1.000		**11.4229**	<-- Max Draw

Figure 44: Hourly DHW Loads Calculations Building: CBC

Building: CT

Appt Size (sq.ft)	No. of appts in the building	Daily DHW rec load (gal/day-apt)	Daily BUILDING rec load (gal/day)	Floor Area (sq.ft.)
531	54	34.7	1873.8	28674
Totals ->	**54**		**1873.8**	**28674**

Hour	Load Distribution Fraction	Hourly Load on DHW (gallons)	Minute Load on DHW (gallons)	Fractional Rate of Max Draw
1	0.019	36	0.60	**0.10**
2	0.014	27	0.45	**0.08**
3	0.012	22	0.37	**0.06**
4	0.012	23	0.38	**0.06**
5	0.019	35	0.58	**0.10**
6	0.032	60	1.01	**0.17**
7	0.053	99	1.64	**0.28**
8	0.063	118	5.92	**1.00**
9	0.063	117	1.96	**0.33**
10	0.063	118	1.97	**0.33**
11	0.061	115	1.91	**0.32**
12	0.057	106	1.77	**0.30**
13	0.052	97	1.62	**0.27**
14	0.045	85	1.41	**0.24**
15	0.038	72	1.19	**0.20**
16	0.038	72	1.20	**0.20**
17	0.045	84	1.40	**0.24**
18	0.053	98	1.64	**0.28**
19	0.057	107	1.79	**0.30**
20	0.051	96	1.61	**0.27**
21	0.047	89	1.48	**0.25**
22	0.042	79	1.31	**0.22**
23	0.035	65	1.08	**0.18**
24	0.028	53	0.88	**0.15**
	1.000		**5.9160**	<-- Max Draw

Figure 45: Hourly DHW Loads Calculations Building: CT

Building: LR

Appt Size (sq.ft)	No. of appts in the building	Daily DHW rec load (gal/day-apt)	Daily BUILDING rec load (gal/day)	Floor Area (sq.ft.)
640	8	35.8	286.4	5120
1032	28	41.6	1164.8	28896
1252	28	44.2	1237.6	35056
1566	28	55.4	1551.2	43848
Totals ->	**92**		**4240**	**112920**

Hour	Load Distribution Fraction	Hourly Load on DHW (gallons)	Minute Load on DHW (gallons)	Fractional Rate of Max Draw
1	0.019	81	1.35	**0.10**
2	0.014	61	1.02	**0.08**
3	0.012	51	0.84	**0.06**
4	0.012	51	0.86	**0.06**
5	0.019	79	1.31	**0.10**
6	0.032	137	2.28	**0.17**
7	0.053	223	3.72	**0.28**
8	0.063	268	13.39	**1.00**
9	0.063	266	4.43	**0.33**
10	0.063	267	4.45	**0.33**
11	0.061	260	4.33	**0.32**
12	0.057	240	4.00	**0.30**
13	0.052	220	3.67	**0.27**
14	0.045	192	3.20	**0.24**
15	0.038	162	2.70	**0.20**
16	0.038	163	2.72	**0.20**
17	0.045	190	3.17	**0.24**
18	0.053	223	3.71	**0.28**
19	0.057	243	4.04	**0.30**
20	0.051	218	3.63	**0.27**
21	0.047	201	3.35	**0.25**
22	0.042	178	2.96	**0.22**
23	0.035	147	2.45	**0.18**
24	0.028	120	2.00	**0.15**
	1.000		**13.3867**	<-- Max Draw

Figure 46: Hourly DHW Loads Calculations Building: LR

Appendix E. Recommendations for future field research

At many points in this research we had to make simplifying assumptions that we have reason to believe may be less than optimal. For example, the team and CEC Staff agreed that it was better to use the gallons per day per square foot usage rate for modeling in this research as were used in the research that established the single family DHW budget equation in the current Standards. We recognized that better field data might justify different rates even for single family residences, and that it seems intuitively reasonable that rates might be different for multifamily residences. Yet we determined that we do not have sufficient data to support any other level of use at this time. Consequently, we tabled the idea of variations, and we now offer the following recommendations for future field research.

1. Seasonal and weekend variations in daily average consumption

For estimating the daily average consumption of DHW, a 24 hour fractional schedule has been used (developed by Davis Energy Group using HWSIM) which is considered to be constant for all days of the year. Previous work by others (Perlman, Lobenstein, Lutz, Eley, Bouchelle) indicates that there are significant daily variations in hot water consumption for week days vs. week-ends, and that there are variations in hot water use seasonally.

The existing data collected on DHW consumption was from residences in New York, Florida, Minnesota and Canada, but none for California. Neither do the data from the previous research provide a consistent assessment of the impact of either day-of-the-week or season on hot water use. More research in this area, specifically on California residences, needs to be completed.

2. Variations in consumption by occupant type

In this analysis we assumed an equal hot water use (gal/sf) by the occupants regardless of the occupant and building type. Previous research by others (Perlman, Lobenstein, Lutz) indicates that hot water usage varies by occupant age, by type of residence (condominium, apartment, etc.), building age and by who pays the bill for hot water. We need additional research to determine the effect of demographics on hot water use and water heating energy use in California.

3. Temperature Control Parametric: Recirc pumps should be cycled on/off by an Aquastat

The model used in this study has been assigned a loop re-circulation flow to maintain an average temperature difference for loop supply temperature and return temperature of about 15deg F. Calculating this delta every hour and adjusting flow requires the simulation program to have an iterative approach, which is not available in the most current version of DOE (version 2.2), which was used for this study. It is expected that the future versions of the program (or EnergyPlus) may have this option. For this study however, a recirc flow was specified, which achieves a delta of 15 degrees F, for a design day.

4. Effect of a laundry center

To model the impact of having separate laundry facilities, rather than individual hook-ups in each residential unit, we simply subtracted the laundry draws from the other residential draws and placed them at a laundry center assumed to be directly adjacent to the boiler. We had no simple way to adjust the draws in a way that represents hours of operation of the laundry center, so all hours for the day were adjusted equally. We added exactly the same amount of hot water draw per day to the laundry center that we subtracted from the individual apartments. Research done by The National Research Center, Inc. (NRCI) in 2001 indicates that apartment dwellers who do laundry with "in-unit" facilities use three time the hot water (and three and a half times the cold water) as those who do their laundry in a common area. Since our current analysis was based on laundry uses accounting for 15%-18% of the total hot water draw, if the results from NRCI can be replicated common laundry centers could represent a 10%-12% reduction in water heating energy. We recommend that this research be replicated in California to determine if refinements to the MF DHW model are warranted.

5. No inlet pump – only aux. Energy

For DOE2.2 simulation, it is not required to provide a pump at the inlet of the loop as the program assumes that the flow into the loop is at sufficient pressure to meet the demand. We find that the common installation has inlet pumps but to model energy used by this pump we had to model auxiliary energy to the water heater. The heat added by these pumps is not modeled, though it will affect the energy usage for water heating. We recommend research on this topic to refine the distribution system model in DOE 2.