Best Practices for Efficient Hot Water Distribution in Multifamily Buildings

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ABSTRACT

Hot water use can be a very large proportion of the energy use in a residential or multifamily building depending on climate and occupancy type. The hot water system is a major subsystem in buildings that is comprised of a series of components: water heater (or boiler); the piping; faucets, showers, tubs and appliances; mixed or hot temperature water running down the drain; and occupant behaviors. These components must be integrated into a system in order to achieve higher efficiencies of hot water distribution. Often, they are not, and we suffer the consequences in wasted energy, water and time.

For most multifamily buildings with central domestic hot water (CDHW) systems, the problems of inefficient distribution are compounded when compared to a more familiar and simple residential layout. Larger volumes of water and greater pipe run distances that are characteristic of CDHW have the potential for much longer wait times, water waste and standby thermal losses. Recent research on CDHW distribution has shown that performance issues in existing buildings are more pervasive than one would expect, but that proven strategies exist that can overcome these challenges, if given an opportunity. This paper will analyze what the existing conditions of CDHW typically look like, best practices for improving efficiencies, the potential impact on a national level, and how utilities and governments can help drive the penetration of these practices.

Introduction

Domestic hot water represents roughly 20% of the overall energy pie for residential homes nationally, including multifamily dwelling units (EIA 2005). This percentage is an increase from several decades ago when HVAC hogs consumed the lion's share of the total energy use, prompting stricter regulations and forcing technological innovation to bring greater control and efficiencies to space heating and cooling. Today, HVAC still remains the largest energy end-use, however due to the technological advances achieved in this area, the HVAC portion of the energy pie has been trending downward while the water-heating portion, which has not advanced as rapidly, has been becoming a greater portion by default. This shifting in energy use has increased attention towards improving the efficiency of water heaters, as well as distribution in buildings. Looking at hot water systems holistically, as an integrated system, is important in understanding how water and energy are consumed in both heating and distribution.

In the past, the water heating industry has focused on energy use at a component level. In other words, the water heating manufacturers focused on increasing the efficiency rating of the water heaters, and the fixture manufacturer's focused on lowering the flow rate of their fixtures, etc. The advances made in these individual areas were done so with seemingly little interest or focus on how the components interacted together as a system. While this has led to higher efficiencies on a component level, it has ignored a key element that has recently been found to be one of the biggest energy consumers for hot water - the distribution system (California Utilities Statewide Codes and Standards Team 2011). In other words, water heaters became more efficient, fixtures became low flow, but the method for distributing hot water to the point of use has had lagged in terms of performance improvement. However, recent research has highlighted both the energy and economic gains of improving the distribution.

A description of what is commonly found for water heating, a summary of recent research, and practical steps to improve hot water distribution along with the resulting impact will be discussed.

The Importance of Hot Water Distribution

Hot water is a staple of our daily life. It is used frequently throughout the day by nearly everyone. According to the Energy Information Administration (EIA), 99% of households use a water heater (EIA 2005). This is why on a national basis hot water is the second largest end use of energy in buildings, after space conditioning (Sachs et al., 2011). For the same reason, hot water is an important area of potential energy efficiency gains. At the same time, the potential for water and energy efficiency will not be fully realized without products that do not impede upon the satisfaction or comfort of the end user, otherwise they will never be implemented. The most important consideration for the consumer is the quality of hot water, i.e., temperature, pressure, time-to-tap, etc. Thus, for widespread adoption of energy-efficient designs, the quality of hot water service must be equal to or greater than what exists currently.

Over the past 10 years, the technology to generate hot water has improved significantly. Water heaters are achieving higher efficiencies[1] as well as extremely low emission levels. Another area of hot water that has progressed significantly is the efficiencies of fixtures. Currently, many water-related upgrade projects are using low-flow aerators rated at 0.5 gallons per minute. Much of these achievements were the results of aggressive building codes and energy programs. This leaves hot water distribution as the last piece of the puzzle needed to advance efficiency gains within the industry. Research started within the last few years is laying the foundation for the future of hot water distribution.

Energy Flow, Uses and Losses in a Multifamily CDHW System

The most recent research on multifamily central domestic hot water (CDHW) energy flows come from a study published in October 2011 by the CA Utilities Statewide Codes and Standards Program. According to estimates provided by research consultants Heschong Mahone

[1] This can vary depending on the technology, on the low end a conventional water heater may be 67% efficient, while tankless and condensing boilers, heat pumps are getting to the 200%+ level.

Group, of the total energy input of a CDHW system, roughly 35% of that energy ends up as usable hot water at the tap. 33% is lost in the recirculation loop, 1% in the remaining distribution pipes, and the rest through inefficiencies by the water heater (California Utilities Statewide Codes and Standards Team 2011). This study says a lot about the impact that hot water distribution has on building energy use and the need to address these losses through improved plumbing layouts, pipe insulation, and recirculation pump controls. According to EIA reports, the costs for water heating in residential buildings in the U.S. are around $32B annually (EIA 2005). Given that distribution makes up a significant portion of these costs, this would infer that there are billions[2] of dollars of waste due to hot water distribution.

After the hot water has been generated, 49%[3] of that heat energy radiates off the pipes and into the surrounding air, most often into unconditioned space. When comparing the components used for hot water generation to that of the distribution system piping, the surface area of the distribution system is almost always greater while at the same time the level of insulation is always less. Furthermore, distribution pipes can often run through areas that are unconditioned. So how do you lower energy waste in these systems? To understand the recommendations provided, the base case for existing systems needs to be established.

The Current State of Hot Water Distribution

Hot water distribution can be characterized as being either a centralized system, or distributed, i.e., individual water heaters per dwelling unit. In the case of the latter, the equipment used and plumbing layout of the pipes most often resembles that of a typical single-family residential system. In a centralized system, however, the components of the system (heater, tank, pump and pipes) are commercial grade, dealing with a greater volume of water and larger pipe architecture. It is common to refer to these central systems as “commercial” water heating systems, even though multifamily buildings may be considered by many to be a “residential” application. In other words, commercial water heaters are used in multifamily residential buildings. The majority of multifamily buildings in the US use a centralized hot water system that requires recirculation systems to provide timely hot water for users. Oftentimes, the ratio of central systems to individual DHW systems can vary depending on the region. “A central domestic hot water (CDHW) system with an insulated re-circulation loop is inherently more energy efficient than a multitude of individual water heaters – and costs less up front.” (Benningfield Group, Inc. 2009).

While codes are becoming more aggressive to achieve energy savings, the vast majority of existing buildings are far below the bar set by current energy building codes. Many current

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[2] If total hot water expenditures is $32B, and subset of sites have hot water distribution that consume 33% of the energy, then the cost of this waste is greater than $2B.

[3] The 49% comes after taking out the losses from the water heater(34%), 33% distribution loss vs. 35% usable hot water, 33/(33+35)=.485.

building codes call for high efficiency water heaters, insulation, and some control of the circulation. Unfortunately, this is most often not the base case.

It is not uncommon to find boilers and water heaters that are 20 years old or more. The main motivation for an upgrade is the death of its predecessor, commonly due to a leak. The frequency of leaks is highly dependent on the water quality and thus the region where the building is located. So even though regulations have increased the minimum efficiencies that can be sold into the market, the useful life of boilers are so long that regulations have a minimal effect on the existing building stock. One report surveyed Southern California Gas Company customers in 2005 to determine the retention rate of various natural gas heating components that were installed in 1995 or 10 years earlier. The researchers found that 100% of the boilers had been retained (Robert Mowris & Associates, 2005). Boilers were the only product to achieve a perfect score (100%) in terms of retention. With water heating technology advancing along with regulations to support their use, the only way to make use of these advancements is to retire the inefficient technology because the existing often last for 10+ years.

Even though the boilers can remain useful for decades at a time, the performance of the boiler sub-components such as the burners diminishes over time along with the other components of the water heating system such as the pumps and tanks, all of which lead to a gradual degradation of efficiency. Another study inspected hundreds of water heating systems and reported on the conditions that were found: 70% of the systems had build-up in tank type heaters, 50% had dirty burner tips, 10% of the pumps had failed, and 80% of the systems had un-insulated piping (KEMA Energy Services, Inc. 2008). In essence, we have very robust boilers that have a substantial useful life, as long as the definition of useful does not include being energy efficient.

The ability to produce hot water can often be misleading when compared to energy consumption, because sometimes the symptoms of a hot water issue can be relieved without ever fixing the problem. For instance, turning up the temperature set-point of the system can relieve the symptoms of not getting enough hot water, quickly, or sufficiently hot. This can cover-up the problem, but the actual cause of the issue may be build-up in the tank or the circulation pump going bad. A faulty mixing cartridge on a shower valve might be the cause of a long wait for hot water (the symptom), but running the circulation pump continuously, an energy wasteful operation, can cover up the problem without fixing anything. The mismatch between cause and solution is mostly due to the lack of education for the maintenance personnel who may not know the distinction between what is an easy cover-up fix and what is correcting the underlying issue.

What does the average central water heating system look like? Based on some of these reports, we can safely assume that the typical existing central water heating system is comprised of the following:

- Aging boiler or water heater (>7 years, approximately)
- Un-insulated pipes
- Uncontrolled circulation pump

- Higher than needed temperature set point
- Other miscellaneous system components not working as intended

One can easily see that there are many combinations of factors that end up affecting the water and energy use of these systems, most often not to the benefit of the consumers.

Factors to Hot Water Distribution Energy Use

What are some of the factors that affect the amount of energy used by the water heating system? How do they interact with each other? Much of the newest research has emphasized the fact that the efficiency of a water heating system is more complex than the combined efficiency ratings of the individual components. The research on how much energy is lost before the hot water comes out of the tap concludes that only roughly one third of the actual energy that is delivered in the form of hot water has a direct correlation with the energy input (natural gas, electric, oil, etc.). This means that the other two thirds of the energy use is wasted by a multitude of other factors beyond the volume of hot water used by the end user. This also includes factors that are based on human behavior that is beyond the scope of mechanical systems. For instance, it's been documented that in colder weather that people will sometimes shower at temperatures that are 10°F hotter and will take longer showers than when the weather is warm. This results in an increase of one therm per person per month or a 15% increase for cold days vs. hot days. Other factors that affect the energy use include:

- Incoming water temperatures
- Tank storage set point
- Climate
- Efficiency of the Water Heater or boiler
- Efficiency of the circulation motor
- Control of Circulation
- Piping layout and architecture
- Level of insulation for the water heater and the distribution system
- Maintenance
- Degraded and failed components
- Water leaks from various sources

Unfortunately, most of these factors are unknown such as the length and diameter of the pipes that are hidden behind walls. Many of the factors vary for any given day, such as the temperature of the cold water feeding the system. Finally the factors that are known are often no longer accurate such as the efficiency rating of the boiler once the burners start to get fouled up. Most of these hot water systems are complex and are only utilizing a fraction of the energy that they are consuming. Although solutions that address these problems are beginning to emerge, this still remains an area that is in need of further study. Future studies need to look beyond each piece and take a holistic view of the system.

Even though there is a lot to learn, what we have learned has not been implemented in any significant percentage of the existing systems. Achieving a greater penetration of efficiency upgrades for hot water can only happen by empowering the building managers with knowledge via extensive outreach and providing further economic motivations. The following sections will discuss efficient design strategies that will move the industry in the right direction.

Optimized Design Strategies

There exists practical and proven ways to achieve efficiencies in a central hot water system, both from a design and a control standpoint. These best practices are often only viable if implemented during construction, with some options becoming less practical to implement after the fact.

Insulation of the Recirculation Loop

Adding one inch of R-4 insulation to the recirculation loop can slow down the cool down period considerably but realistically this can only happen during the plumbing phase of construction or a major re-piping project. The vast majority of existing multifamily residences do not have any insulation on the recirculation loop or distribution pipes, as it has only been a code requirement for less than a decade. Existing multifamily buildings generally do not have access to the pipes, rendering insulation projects cost-prohibitive and impractical.

Demand Controlled Recirculation System

Turning the hot water system's recirculation pump off when it does not need to run remains one of the easiest and most cost-effective strategies for reducing overall distribution heat losses in a single or multifamily building. The most effective means tested for recirculation pump control is demand controls. This works by monitoring demand in the building (either by a flow switch, motion sensor or any other real time demand sensing capabilities) and water temperature on the return line of the recirculation loop. The pump will only run when there is real time demand for hot water and when the water in the recirculation loop has fallen below a usable temperature. Applying this sequence of operation minimizes the recirculation of hot water and accurately matches hot water delivery to hot water usage. Since all the control points for this method of recirculation are within the boiler room, this is a simple retrofit for existing buildings. Yet, while this is a quick and cost-effective measure, the only known area that has widespread implementation of demand controls in multifamily buildings is within Southern California Gas Company service territory, which is due in large part to its funding of a 3rd party, direct install efficiency program called "On-Demand Efficiency", managed by Benningfield Group.

Optimized Recirculation Loop Design

Shortening the length of a recirculation loop has also been shown to help keep distribution heat losses to a minimum. The standard practice for central hot water system-design in multifamily has been to have one recirculation loop servicing an entire building's hot water load. Some new research indicates that greater efficiencies are achieved by keeping the boiler room in a central area of the building and operating separate recirculation loops for each wing of the building. Unfortunately, this is only feasible on new construction and major renovation or re-piping projects.

Monitored Operation

A hot water distribution system should have the capability of being monitored for proper operation and for fault detection. For many multifamily buildings, the central hot water system is left unattended until such time that a tenant complains of some unsatisfactory condition or there is a noticeable spike in utility consumption. These issues may, potentially, persist over a long period of time. Having the ability to track various hot water distribution data points in real times using a web access interface allows for building operators to easily track and check for common issues such as excessive temperature settings and pump operation, cross-over, pipe leaks, boiler short cycling and a host of other problems. An effective monitoring and control system can also include the ability to send an automatic alert the instant a problem is detected, as well as issue reminders for maintaining proper preventative maintenance schedules. This is a good practice for existing buildings as well as new construction. The main barriers include the feasibility of getting communication to the boiler room, and the ongoing cost of a communication method whether it is internet-based, cellular or by other means.

Overcoming Barriers

A number of barriers exist that are keeping these basic strategies from gaining traction in the market. The first and most glaring aspect of this picture is that the plumbing industry has not yet embraced the importance of hot water distribution and the connection it has on water and energy consumption. Fortunately, the newest building energy codes and standards are taking into consideration more advanced recirculation pump controls, insulation requirements and plumbing design to meet the government's increasingly aggressive energy goals. California's Title 24 energy codes, for example, will be making demand controlled recirculation systems a minimum prescriptive requirement for all new multifamily buildings starting in 2014. The International Code Council is also coming out with an environmental mechanical code supplement called the International Green Construction Code (IGCC). In this code, service hot water systems must have a demand controlled recirculation pump and previously prescribed control strategies that work on a timer or temperature based control do not qualify to meet the standard. Finally, LEED® certification for single and multifamily buildings now provides credit for buildings that have efficient distribution.

Even with building codes and standards improving, this only addresses the new construction or major renovation market and does not address the existing building stock, where the true opportunity for energy savings lay. The larger barrier to overcome is in convincing building owners to outlay capital for efficiency improvements that may be perceived as unnecessary or risky. Plumbing contractors who are not familiar with the nuances of selling energy efficiency products or measures will be ineffective in creating any meaningful market transformation.

The Need for More Comprehensive Programs

To date the most reliable and effective means in scaling adoption of advanced distribution controls in existing multifamily buildings is through rebates and incentives offered through utility or municipal programs. Currently, there are roughly 1000 or so utility and government run efficiency programs that deal with water heating in the United States (www.dsireusa.org). These programs promote and provide incentives on a number of water heating related measures, including: boiler or water heater replacements, boiler tune-ups, piping insulation and boiler temperature reset controls. There is no doubt that these programs have created the impetus for owners to upgrade their systems and thus save energy, yet these programs have the potential to be more far-reaching both in their in their breadth of measures and approaches to customer outreach. For example, although enough data exists on the efficacy of advanced distribution controls, such as demand controlled pumps and remote monitoring systems, there are still only a few utilities that actually offer these technologies as part of their program offering. Given the opportunity for capturing large scale and cost-effective energy savings, more utilities need to evaluate and eventually incorporate these and other proven technologies to create a more robust program offering.

Potential Impact Nationwide

As the barriers to efficient hot water are overcome, we will be able to achieve substantial savings. One report that investigated the potential for the multifamily segment stated, "Policy-makers looking to garner savings in multifamily housing stock need to recognize that the geometry of multifamily buildings means that less of the savings will come from building envelope and HVAC measures, and more will come from water heating efficiency gains and appliances; and that there are significant opportunities for bundling energy uses to gain an economy of scale when making efficiency improvements (e.g., central hot water systems)." (Benningfield Group, Inc. 2009). Another report that examined a wide variety of technologies for hot water across multiple building types including multifamily housing found that "sixteen technologies can save 2.29 quadrillion BTU through 2025, or about 5.3% of projected demand in residential and commercial buildings in year 2025. Collectively they save an average of 37% of energy over federal minimum efficiency standards for water heaters and conventional water heating systems." (Sachs et al.,2011).

Conclusions

Multifamily water heating is emerging as a prime target for saving energy. There is a large opportunity to harvest energy efficiency gains and will remain so in the near future.

The energy industry must realize that the existing condition of water heating systems are far below current standards and in need of both research to understand the plethora of factors that influence the energy use in these systems, as well as actual implementation of the existing technologies that are under-utilized. The easiest pathway for the widespread use of efficient hot water technologies involves a comprehensive set of incentive programs, which has been proven to facilitate market transformation. Within the subject of hot water, the technological advancement of hot water generation has improved a great deal over the past several decades, while the area of hot water distribution is only at the beginning of its progression cycle. Therefore, hot water distribution needs to be an area of attention.

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