

## Technical Paper: Even Heating of Hot Water Radiators

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### Introduction

Hot-water heating has been around for generations and it provides a combination of comfort and efficiency that cannot be matched by forced-air systems. Millions of homes worldwide are heated with the same hot water radiators that were installed decades ago. Despite the benefits, these systems do have one very common problem: the radiators do not all heat up evenly. Almost any homeowner can tell you which are the ‘hot’ radiators and which are the ‘cold’ radiators in their home. However most of them never complain to their HVAC service provider, because the problem has always existed—they assume that there is no solution.

### Why is Even Radiator Temperature Important?

Even small temperature differences between radiators can have a large impact on the heating comfort in a room. The heat given off by a radiator varies with the temperature of the radiator raised to the power of 1.8 (approximately) -- as a result, in a room at 72°F, a radiator at 100°F is putting out only 58% of the heat put out by an identical radiator at 110°F. When these small temperature differences are removed, homeowners notice immediate and striking improvements in heating comfort.

### The Focus of this Technical Paper

There have been many attempts to solve the problem of uneven heating of the radiators, but until now, there has been no simple and economical solution. The majority of the efforts to-date have focused on trying to adjust the amount of hot water flowing through each radiator. While good plumbing and system balancing can reduce the problem, it can never eliminate it under all conditions because the root of the problem lies in the control of the circulator pump. This technical paper explains why it is so difficult to obtain evenly heated radiators using valves with standard circulator controls, and how *the Smoother* delivers the same heating comfort as continuous circulator operation while reducing electricity usage by approximately 75%.

### The Problem with Standard Circulator Pump Controls

Most boiler circulator pumps are controlled by a temperature switch. When the burner begins firing, the temperature switch keeps the circulator pump turned off until the burner heats the boiler water up to a ‘setpoint’ temperature (usually around 120-140°F). Once the setpoint is reached, the switch turns the circulator pump on and hot water begins circulating. The flow of cooler return water reduces the boiler water temperature below the setpoint and the switch shuts the circulator pump off again. The result of this type of heating and circulating cycle is to send out pulses of water at approximately setpoint temperature. A greater heat demand generates a longer burn cycle which translates into more pulses of hot water being sent out.

Ideally, each radiator would receive a proportional share of the hot water during each burn cycle. For example, during colder weather, a burn cycle might be long enough that each radiator would receive hot (assuming setpoint temperature ~ 140°F) water equal to 2/3 of its volume, which would bring the radiator temperature up to approximately 120°F. In milder weather, a shorter burn cycle might deliver hot water equal to only 1/3 of the radiator volume, bringing the temperatures of all radiators up to only 100°F.

**Unfortunately, this ideal situation does not, and cannot happen.**

### Single Pipe System

A single-pipe system, in which the radiators are connected in a loop, often gives the least even heating. In this system, the hot water from the boiler reaches each radiator sequentially, heating them up one-by-one close to setpoint temperature. Once the room with the thermostat has received adequate hot water, the thermostat shuts off. In all but the coldest temperatures (longest burn times), this will occur before the last radiators in the loop receive any hot water. They receive only the lukewarm water which has been cooling in the earlier radiators since the previous burn cycle. On the other hand, the first radiators in the loop will heat right up to setpoint temperature after even the shortest burn.

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## Two Pipe System

Two-pipe systems were created as an attempt to improve on the uneven heating of single pipe systems. In a two-pipe system, there are many loops connected in parallel: the flow from the circulator is divided among them. Often, there is a separate loop for each radiator, with a valve to regulate the flow through that radiator. Ideally, this would allow every radiator to begin receiving hot water at the same time and to heat up uniformly. Unfortunately, in practice **this is impossible due to the different lengths of pipe leading to each radiator.**

A radiator located close to the boiler has very short pipes leading to it. The water volume in the short pipes is small compared to the water volume that the radiator holds. Radiators located further away from the boiler have very long pipes that hold much larger volumes of water—in some cases, there is more water in the pipe leading to the radiator than in the radiator itself. As a result, the closest radiators begin heating up with the first pulse of hot water from the boiler, while farther radiators stay cold through many pulses, until the hot water has made its way through the long pipes.

In mild weather (shortest burn cycle with a small volume of hot water sent from the boiler) the burn cycle may end before *any* hot water reaches the farthest radiators. Because pipes have a high ratio of surface area to volume, they usually cool more quickly than radiators. Often the pipes will be cold by the time the next burn cycle begins. Thus, the farthest radiators will wait through repeated burn cycles without ever warming up.

Adjusting the valves so that much more water flows to the farthest radiators will reduce the burn time needed to get heat to them, but will upset the balance for longer burn times. The following example illustrates this phenomenon:

Picture a system in which all pipes are the same diameter, and your goal is for all radiators to begin receiving hot water at the same time. If the pipe to the farthest radiator is five times as long as the pipe to the nearest radiator, then the valves must be adjusted to give five times more flow through the farthest radiator than through the nearest one. Both radiators will begin receiving heat at the same moment, but as the burn continues, the farthest radiator will be receiving hot water five times faster than the nearby radiator.

The only way to achieve perfect temperature balance with a temperature switch would be to design a two-pipe system in which the ratio of pipe volume to radiator volume is the same for each radiator. This could be done by using very narrow pipes for the farthest radiators and very large-diameter pipes for the closest radiators, the opposite of what is commonly done. Or, if the pipes were the same diameter, the pipes to the close radiators would have to be coiled or doubled back on themselves to increase their length. In either case, the system response would be slowed down due to the extra water volume in the system, and a great amount of heat would be lost from the pipes, not in the places that need to be heated. And of course the cost of this elaborate plumbing would be very high.

Valves can be adjusted to be properly balanced for one outdoor temperature, but not for all. Balancing the radiator temperatures using valves is an imperfect compromise: the valves would have to be adjusted differently for every different outdoor temperature. The compromise setting in most homes results in cold radiators in the outlying rooms, especially in milder weather.

## ***The Smoother***<sup>™</sup> Heat Balancing Circulator Control

Unlike standard circulator pump controls, *the Smoother* operates on a completely different principle: *the Smoother* uses the circulator pump as a mixer, to keep the temperatures in every part of the system as equal as possible. It does not require the flow through any part of the system to be controlled or regulated—as long as a radiator has at least a small amount of flow through it, its temperature will be equalized with the rest of the system. *The Smoother* was designed to provide all of the comfort advantages of continuous circulation (see below) but without the excessive electricity usage. It operates the circulator pump exactly when needed to achieve optimum heating comfort.

*The Smoother* runs the circulator pump continuously during burner firing, and after the burner cycle ends, the circulator pump continues to run to “stir” the water long enough that even the furthest or lowest-flow radiator is brought to the same temperature as all the rest. By running the pump continuously during all burner firing, the build-up of temperature gradients among the radiators is limited to the temperature rise across the boiler. Even in a single-pipe system, the temperature

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difference between the first and last radiator will never be greater than this temperature rise, which can be calculated as follows:

The temperature rise is approximately equal to the output of the boiler in kBTUs/hr divided by the flow rate of the pump in gpm, multiplied by 2. For example: a single-pipe system with a 120,000 BTU/hr boiler, and a 12gpm flow rate:

$$\begin{aligned} 120 / 12 &= 10 \\ 10 * 2 &= \mathbf{20^{\circ}\text{F}} \end{aligned}$$

Thus with *the Smoother*, the first radiator in this system will never be more than 20°F hotter than the last one, regardless of the length of burner firing. With a temperature switch, the first radiator would often be 140°F, with the last radiator completely unheated at 72°F (a 68°F difference).

After the burn ends, the small temperature differences that have built up during the burn are quickly stirred out by the additional circulator running time. In a temperature switch system, the much larger temperature differences remain, resulting in uneven heating, occupant discomfort and energy waste.

*The Smoother* has five different settings for the additional stirring time. This simple setting meets the needs of any system. The “stir time” setting is set based on radiator type, home size, and pump power. Systems with all cast-iron radiators and reasonably good flow through all radiators can use the lowest settings, because the temperatures of every radiator will equalize quickly. After the pump shuts off all the radiators will cool uniformly, so no further circulation is needed. For systems with fin-tube radiators, other low-thermal-mass radiators, or a radiator in a very cold or drafty room, a higher setting is used. This circulates stored heat from the boiler and any cast-iron radiators out to the other radiators which would otherwise cool quickly after pump shut-off. The stir-time setting is not dependent on the time of year or outdoor temperature, therefore it only needs to be set once.

### Continuous Circulation

Many established HVAC contractors have known about the uneven heating problem for years, and they often use a simple solution: they run the circulator continuously. This achieves the same comfort benefits as *the Smoother*, because the pump is of course on at all of the times when *the Smoother* would have the pump running. However, the pump spends a lot of time running when it doesn't need to. As a result, continuous circulation wastes a lot of electricity: a small 2 amp pump running for one year uses over 2000kWH of electricity! The Smoother can save 75% of this--at \$0.10/kWH (total delivered cost) *the Smoother saves over \$150 every year!*

Most homeowners understand intuitively how wasteful and inefficient it is to run the circulator continuously and are eager to find an alternative. There has also been a tendency in recent years to use smaller and smaller circulators to reduce electricity use, however this has brought its own problems. Even with continuous circulation, temperature differences get larger as pump flow is reduced. In some cases, the tiny pumps cannot overcome gravity to drive hot water down to basement radiators. *The Smoother* allows the circulator to be sized properly, big enough to do the job, while using less electricity than a tiny, inadequate circulator running continuously.

### Condensation and Bypassing

The same precautions against condensation need to be taken when using the Smoother as when using continuous circulation. If the boiler is a non-condensing type which requires a minimum water temperature, then proper bypassing is needed to ensure that condensation does not occur. We recommend a boiler bypass (rather than a system bypass) for best heating comfort, however in all cases the boiler manufacturer's instructions must be followed.

### Limitations

The Smoother gives all of the comfort benefits of continuous circulation. However, it also has some of the same limitations. If a radiator or pipe is completely blocked then no heat can reach it. In addition, if the circulator is badly undersized, then it may not be possible to drive heat down to basement radiators. And of course if radiators are improperly sized for the rooms, even perfectly even radiator temperatures will not provide even room heating.

Nonetheless, *The Smoother* does not require perfect plumbing to deliver even heating. Even very poorly balanced systems can be completely evened out, with no plumbing work needed. And even the best-plumbed systems will see immediate, noticeable improvements in comfort.

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### Additional Benefits of *the Smoother*

The design principles used to develop *the Smoother* are based on bringing together all the best circulator control features in one simple, cost-effective solution that really works. In addition to the heat-balancing circulator control algorithm, *the Smoother* also has:

- a circulator pump exercise feature, which operates the pump for 2 minutes once per day to help prevent summer-time pump seizure and keep seals fresh
- a soft-start to reduce shock, heat, and noise on pump start-up and extend the circulator pump operating life
- a rugged, all solid-state design that is fully surge-protected
- simple installation by any HVAC contractor in approximately 30 minutes

*The Smoother* is a valuable and beneficial upgrade to virtually all single-zone hydronic systems. HVAC contractors will find that many homeowners will be retrofitting their existing boilers with *the Smoother*, and asking for it to be installed with new replacement boilers.



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