

Reverse-Return Reexamined

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A common perception is that a reverse-return hydronic piping configuration uses more piping and, therefore, is more expensive than its direct-return counterpart. For example, a hydronics primer recently published in *ASHRAE Journal*¹ briefly discusses direct versus reverse-return piping arrangements and quickly reaches that conclusion. While the cost disadvantage of reverse-return is true in some instances, this column presents a case that reverse-return doesn't always add piping length and system cost, depending on system configuration. In addition, this author has found reverse-return is sometimes overlooked or dismissed out-of-hand when it offers tangible benefits and could easily have been implemented at no net cost to the project. So, a goal of this column is to encourage pipe system designers to explore and consider reverse-return in further detail.

To review, a direct-return system (*Figure 1*) is one in which the terminal nearest the supply source has both the shortest supply water path and shortest return water path to and from the source, while the terminal most remote from the supply source has both the longest supply water path and longest return water path. This can result in significantly different network piping losses from one terminal unit to another, requiring some type of correction (e.g., balance valves, active flow-limiting devices, or perhaps pressure-independent control valves) to keep the system balanced and piping losses equal.

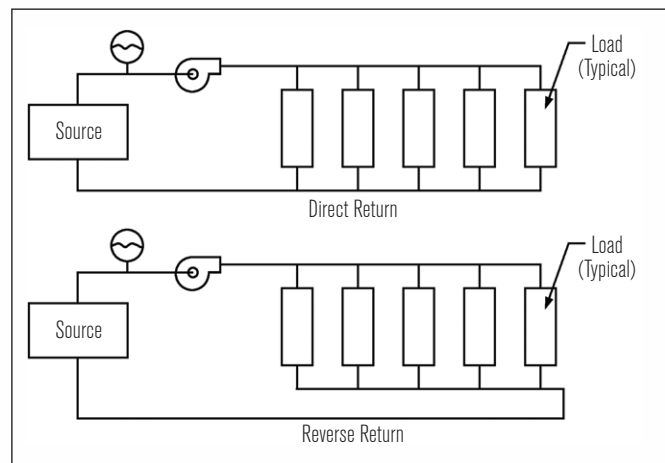


Figure 1: Simplified direct- and reverse-return two-pipe systems.³

By contrast, a reverse-return system is one in which the terminal nearest the supply source has the shortest supply water path but the longest return water path, while the terminal most remote from the supply source has the longest supply water path but shortest return water path. A reverse-return system means that the sum total of supply and return piping losses are

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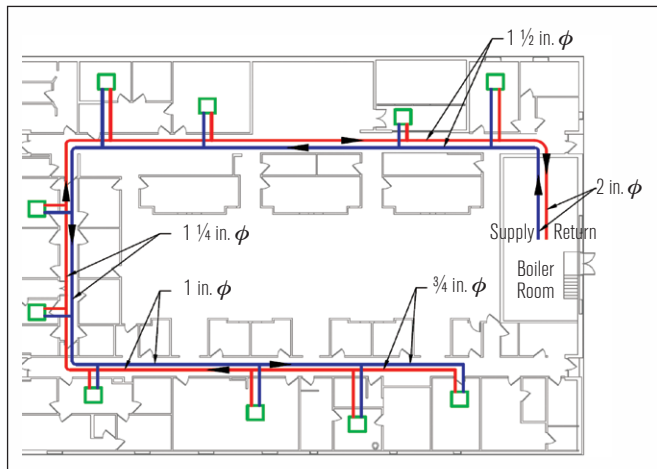


Figure 2: Single-story office building using a direct-return piping arrangement

approximately the same length throughout the water system, making for a more even water flow to all terminals without additional correction. The reverse-return system is nearly self-balancing because the hydraulic distance traveled by the fluid is close to the same regardless of which terminal coil a given volume of fluid flows through; or said another way, reverse-return creates approximately equal hydraulic resistance through each flow path.

Benefits of Reverse-Return

The primary advantage of reverse-return is elimination of balance valves at each terminal coil (VAV reheat box, finned-tube convectors, fan-coil unit, chilled beam, etc.) and the testing, adjusting and balancing labor cost associated with that. Since the material and labor cost of many balance valves and the labor cost of manual balancing is eliminated, a small cost add for the reverse-return piping can be offset by the reduction in balance valves and manual balancing, or a reduction in active flow-limiting devices, or allow the use of standard control valves in lieu of the more expensive pressure-independent control valves. (The remainder of this column will assume balance valves and manual balancing for direct-return systems; but the reader can interpret these and other forms of system balance correction as well.)

While reverse-return systems are close to self-balancing, they are not exactly. Anything that creates a difference in the resistance of the supply or return piping from one flow path to another will change the resistance of that path relative to the others and affect the balance slightly, as would a different type of coil or differences in the coil runout piping itself (length, type, number of bends, size, etc.).

But, these differences are minor and are easily corrected by a standard coil control valve. If one coil path receives a little more than its fair share of fluid flow, the control system will eventually correct for it by repositioning the coil control valve. It is only those systems with large hydraulic differences from leg to leg, such as those found in direct-return systems with some coils very near the source and other coils very remote, that may exceed the pressure range ability of the control valve to perform adequately.

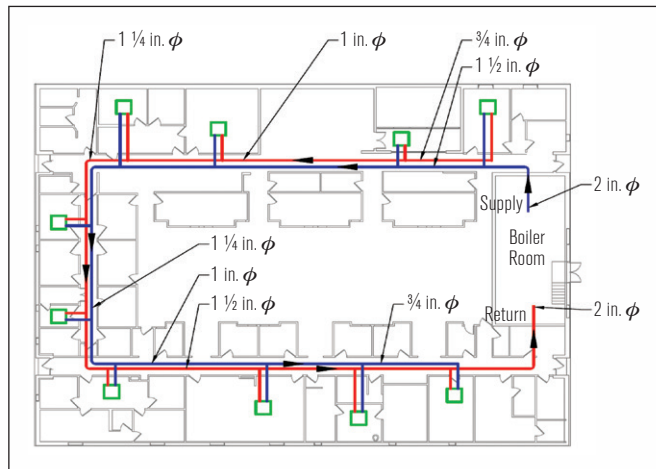


Figure 3: Single-story office building using a reverse-return piping arrangement

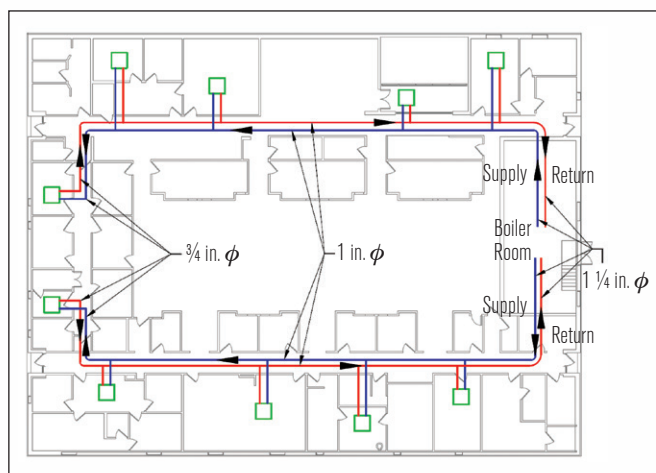


Figure 4: Single-story office building using two direct-return piping paths

Not convinced that reverse-return allows the elimination of balance valves? See Taylor/Stein.² In fact, that article argues that in many cases balancing is not necessary in direct-return systems either, and some engineering firms routinely don't require balancing of direct-return systems. However, that concept makes other engineers and designers uncomfortable, and in this author's experience, the majority of direct-return systems in design practice today still feature coil balance valves.

In any case, the Taylor/Stein article clearly demonstrates that minor differences in balance from leg to leg, such as that found in reverse-return designs, do not warrant balance valves; so this column assumes balance valves in direct-return, but none in reverse-return piping.

In a building that is likely to be remodeled or reconfigured several times over the life of the piping system, such as a speculative office building with tenant turnover, elimination of balance devices can be a significant advantage. In this case, if the primary building HVAC system is conventional VAV with

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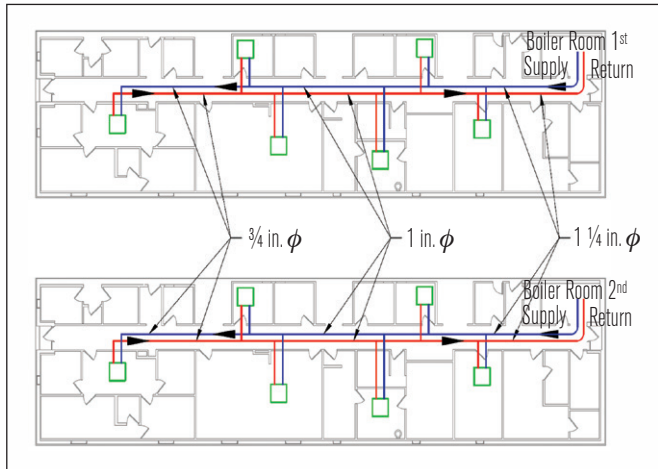


Figure 5 Two-story office building using a direct-return piping arrangement per floor.

many reheat boxes, adding, subtracting, and relocating VAV reheat boxes in a reverse-return system does not require manual rebalance of the hydronic piping.

Building owners are reluctant to send technicians climbing above ceilings in occupied portions of the building not otherwise impacted by renovations, so a balanced direct-return system may not stay that way; whereas a nearly self-balanced reverse-return system will remain nearly so after even several renovations.

For a two-pipe water-source heat pump system, with both heating and cooling inputs to the loop, a reverse-return system allows the heating and cooling source to be widely separated. This can be useful with cooling towers on the roof and boilers in the basement, in which case direct-return doesn't work. Both the heating and cooling sources need to be upstream of the supply loop in direct-return. The heating and cooling sources can be separated at two extremes of the distribution loop if they are connected by the reverse-return leg.

Finally, there is a misconception that reverse-return adds total system head pressure because of the long return line, but a closer examination will show that to be untrue. Using Figure 1 as an example, in the direct-return system, the pump must push the water to the farthest terminal and all the way back to the source again. Each of the other branches to the other terminals must include some artificial means of increasing the pressure drop to simulate the losses of the longest run.

In the reverse-return system, the longest run (or, any run through any of the terminals) is no longer than the longest run in the direct-return system. In fact, reverse-return usually results in somewhat lower pump head than direct-return. This is because (a) the reverse-return main is a large pipe and large piping usually will have lower friction rates than smaller piping, which is stepped down as flow reduces, keeping friction rates near design limits; and (b) because even a fully open balance device has some pressure drop, which can be eliminated with reverse-return.

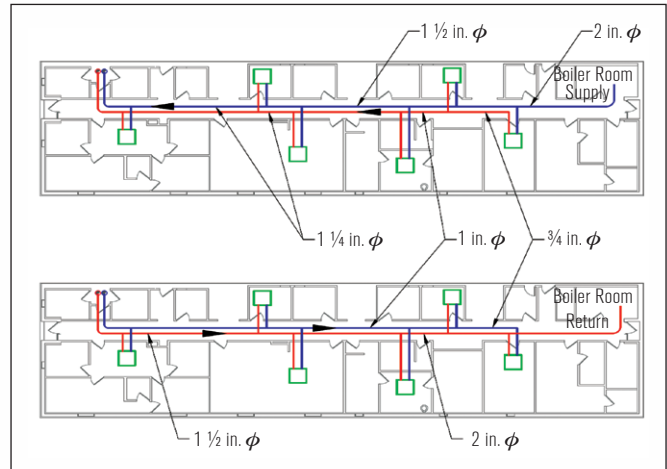


Figure 6 Two-story office building using a single reverse-return piping network.

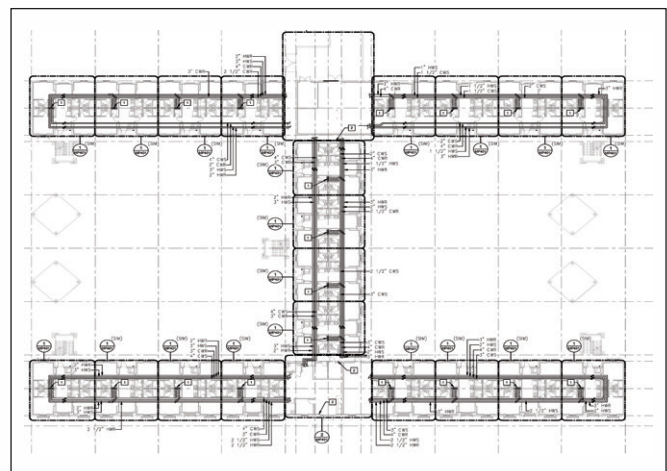


Figure 7 Three-story H-shaped building poorly suited for reverse-return.

Case 1: Reverse-Return is Advantageous

If, for example, the piping system is designed to make a complete loop around the inside perimeter of one floor of a building, starting and ending at a mechanical room or similar base point, the difference between direct and reverse-return piping quantities is zero to negligibly small. To illustrate, see Figure 2 and Figure 3. It is envisioned in these figures that the piping is a hot water heating system and the terminals depicted are VAV reheat boxes, but they could easily be finned-tube convectors, or fan-coil units, or even chilled beams in a chilled water system.

It is also envisioned that the center core is "impenetrable" by piping (e.g., an open atrium, or courtyard, or banks of elevators and stairwells, etc.), forcing the hydronic piping to route around the perimeter.

Compare Figure 3 with Figure 2 and notice that overall system pressure drop (and pump head) is reduced with reverse-return in this case. The worst hydraulic path—the path that determines overall system pressure drop and pump head—in Figure 2 (assuming all coils and branches are the same) is the last one in the string.

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Supply water flows about three-fourths of the circumference of building to the coil, then returns three-fourths of the circumference of the building back again, for a total of 1.5 times the building circumference. In *Figure 3*, all possible hydraulic path pipe lengths equal about one circumference of the building. So reverse-return will reduce total friction, reduce pumping energy, and eliminate balance valves, all while not increasing piping cost.

Case 2: It's a Toss-up—Further Study Needed

This author has actually seen *Figure 2* applied many times when clearly *Figure 3* would have been advantageous. But there is a third option, as the astute reader may have already anticipated—splitting the full circumference of the building into two halves (*Figure 4*) and using two separate direct-return circuits. Now the reverse-return of *Figure 3* is not quite as favorable because the mains start and end larger than those of *Figure 4*. The reverse-return of *Figure 3* still handles load diversity better than *Figure 4* and still offers the advantage of eliminating balance valves and balance labor, both present and future.

In another example, a long, narrow two-story building with a mechanical room at one end can use reverse-return by traveling outbound on the first floor and inbound on the second floor with only a small difference in piping cost (*Figures 5 and 6*). In smaller piping sizes, the cost of labor to install the piping, insulation, hangers, and so forth tends to dominate and lessen the differences in pipe material cost by size, so the net cost after deducting balancing may be similar. Both of these examples—*Figure 3* versus *Figure 4* and *Figure 5* versus *Figure 6*—merit a closer look and neither should be dismissed out of hand.

Case 3: Direct-Return is Advantageous

Reverse-return piping is generally not a good choice when the distribution system dead-ends, such as in an elongated narrow (or “long-and-skinny”) single-story system. In that case, the reverse-return piping requires a third pipe to carry the full system flow from the far end back to the mechanical room or starting point. While this arrangement still provides the self-balancing benefit, the addition of a third pipe running the entire length of the system may add significant cost. On the other hand, if that building is two stories, reverse-return may still be applied cost-effectively, as discussed in Case 2.

In some cases, reverse-return results in a significant increase in piping cost and would then be difficult to justify. An example of a hopelessly misapplied reverse-return system in this author's recent project experience is that of the H-shaped three-story building (*Figure 7*). The request for proposal (RFP) on that project required a four-pipe fan-coil system room-by-room, and it insisted on reverse-return. Making matters worse, the RFP required balance valves at every fan-coil unit even though reverse-return was specified, eliminating the one potential saving grace of reverse-return.

The routing of the reverse-return lines was particularly convoluted due to the H-shape and the three stories, rendering the four-pipe system to become essentially a “six-pipe” system: (1) outbound hot water supply, (2) outbound hot water return, (3) inbound hot water

return, (4) outbound chilled water supply, (5) outbound chilled water return, and (6) inbound chilled water return in each “arm” of the H-shaped building. The RFP's author could not be swayed otherwise, but clearly this was a poor application for reverse-return.

Case 4: A Hybrid is Advantageous

Not to be overlooked is the case of a multistory building. Revisit *Figures 2 and 3* and now imagine they represent a 10-story building consisting of a similar floor plan on each level. Instead of the boiler room found in *Figures 2 and 3*, imagine that location represents a vertical pipe shaft with a boiler either in the basement below or on the roof above. In this case, the most advantageous design may be a hybrid, with reverse-return on each individual floor as depicted in *Figure 3*, but with direct-return on the main vertical riser.

Because the piping makes a complete loop around the inside perimeter, almost no difference exists between direct- and reverse-return piping quantities on the floor. But reverse-return on the main vertical riser would require a large additional return pipe to take flow from the 10th floor to the basement, so that portion of the system remains direct-return.

This author has used this hybrid design many times, using a single balance valve in only one location per floor (near the shaft) to balance the flow to that floor, while allowing the self-balancing nature of reverse-return to eliminate all the balance valves at individual coils. If each floor has, say, 40 hydronic coils, this 10-story hybrid system reduces the number of balance valves from 400 to 10, while still retaining most of the advantage mentioned earlier in terms of future renovations.

Conclusions

Reverse-return piping is a beneficial design option in some cases. Don't automatically assume it adds first cost; it can be cost-neutral in many applications and less expensive than some balancing options such as pressure-independent control valves. And don't fall into the trap of thinking it adds system pressure drop and/or increases pump head; pump head will be the same or lower. Engineers and designers laying out hydronic systems should be familiar with reverse-return and consider applying it when appropriate, as well as understand its limitations and recognize applications where it is not beneficial.

Acknowledgments

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