Q During winter, why do hot-water pipes freeze and burst more frequently than cold-water pipes?

A Foster Lyons, an engineer and building-science consultant, responds: The short answer is because hot-water pipes aren't attached to toilets, which help reduce the number of burst cold-water pipes. Here's why.

Water expands when it freezes, increasing in volume about 9% from its liquid state. That's why ice floats—it's less dense than liquid water. This increase in volume is the proximal cause of ruptured water pipes when they freeze but probably not for the reason you think. Expanding ice doesn't push against the pipe walls to cause the rupture; instead, it's high-pressure liquid water that does the damage.

Pipes that freeze are cooled from the outside in. The warmest location is always the liquid in the center of the pipe. As temperatures drop below freezing, the water starts freezing on the inner surface of the pipe in a slow process that allows plenty of time for liquid water molecules to get out of the way as their neighboring, recently frozen, solid molecules rearrange themselves into that 9% larger arrangement. This freezing progresses from the area near the pipe wall toward the center of the pipe—the opposite of tree ring growth but similar to plaque building up in our arteries.

If there are nearby nonfrozen areas, the last drops of liquid in the center are pushed to liquid areas on either side of the frozen area. When the pipe is frozen through and through, the pressure on the pipe walls exactly matches the pressure of the surrounding liquid outside the frozen zone. The water that is finally pushed out of the middle goes toward either the water source (like the water main in the street or the hot-water heater) or the plumbing fixtures at the end of the line (like a sink or toilet).

The relocated water that goes toward the source doesn't cause much trouble. Usually there are plenty of places to relieve that pressure—a huge volume of water in a municipal system, a hot-water tank, or a well-system storage tank, for example. It's the relocated water that is pushed toward the end of the line that causes problems, and here is where bursts happen.

In a hot-water line, that relocated water has no place to go. At the end of every line is a valve, and—assuming you're not running the tap continuously—those valves are shut. Basically, as ice freezes in hot-water pipes, it pushes liquid water up against a dead end.

It is difficult to compress water. A 1-atmosphere increase in pressure results in only a 0.005% reduction in volume. Considered in reverse, the pressure skyrockets if you cram even the tiniest fraction of additional water into the same volume. That's what happens in those hot-water lines.

For a long time, scientists couldn't figure out how to build anything strong enough to measure the pressures that are generated by the expansion of a freezing water-ice mixture. They tried thick, brass containers and even cannons and artillery shells, but nothing could hold back the pressure generated by expanding ice, and, every so often, they accidentally blew up their concoctions and launched projectiles hundreds of feet. In comparison, the walls of copper pipe are about the strength of tissue paper as far as ice expansion is concerned.

Freezing ice can exert pressures up to 43,511.31 pounds of force per square inch (psi). Domestic water pipes are designed to withstand about 1,500 psi (3/4-inch drawn copper)—depending on pipe size and manufacturing process—which is not even a road bump when you're on your way to 43,000 psi. Freezing water generates the sort of pressure that breaks mountains in half and is a death sentence for copper pipes that get caught between an ice blockage and a closed valve.

On the other hand, cold-water pipes have a relief valve—toilets. That's because toilets have a float valve—more properly called a ballcock—that is operated by pressure differences across the valve. When pressure builds up, the valve opens and releases some of the fluid, and the pressure is reduced. In toilets, this release pressure is controlled by the position of the air bladder. When the supply water pressure builds up in a cold-water pipe feeding a toilet, it pushes the air bladder down into the tank water and that allows just a little bit of water to pass through the valve, thereby releasing the supply pressure.

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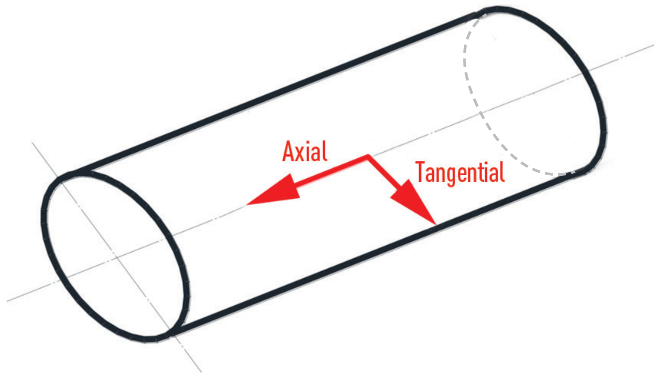
As water freezes in a water pipe and turns to ice, it expands and pressurizes the liquid water remaining in the pipe. Because water is difficult to compress, the pipe will burst if there is no other means for relieving the increased pressure.

As water continues to freeze along the length of the cold-water line toward the toilet, it keeps pushing liquid water through the float valve and the pressure never builds up in that supply line. It freezes, but never bursts, because the pressure in the line never exceeds the pressure setting of the float valve.

Of course, if there are two frozen locations in a cold-water line, the volume between those locations has nowhere to release its pressure, and the pipe will burst. That happens plenty. The same is true for hot-water lines.

Another interesting thing with freezing water: The water in the hot-water lines freezes faster. This is insanely counterintuitive but true. You can easily demonstrate this by pouring two equal cups of water, heating one of them up, and putting both cups into the freezer. Nine times out of 10, the heated cup will freeze first. This unsolved mystery of science is called the Mpemba effect, and nobody can fully explain (with proof) why it happens.

Water pipes burst in the same way as overcooked sausage—always along their length, not at their ends. Like the filling inside a sausage skin, water inside a copper pipe can cause only two stresses on the enclosure material: axial (which tends to change the length of a body) and tangential (where the direction of the deforming force is parallel to the cross-sectional area).



Tangential stress caused by internal pressure in a water pipe acts perpendicular to axial stress and tends to separate a pipe wall in a line parallel to the pipe's center line.

When you work through the math, you find that the axial stress is always half the tangential stress for any given internal fluid pressure. So, the sausage and the water pipe always burst along their length because that's where the greater stress exists.