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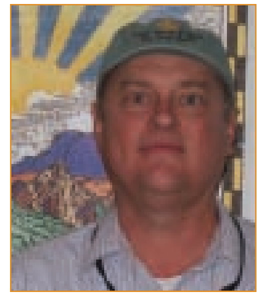

Bristol's six principles of good solar hydronic design

Part 8: Solar heat control with two-stage thermostats

In previous articles, I have been making the case that the key ingredients for solar/hydronic design and installation can be divided into six categories, listed below, roughly in order of their importance.

1. RELIABILITY
2. EFFECTIVENESS
3. COMPATIBILITY
4. ELEGANCE
5. SERVICEABILITY
6. EFFICIENCY

The success of any solar hydronic home heating installation depends on the often-conflicting balance between any of these six principles. Finding the balance between them defines the art of solar heating design.

Good solar heating design requires effective and reliable control of the solar heat. Even the earliest active solar heating systems that used thermostats relied upon some type of two-stage control. Let's take a closer look at two-stage thermostats and some of the finer points related to differential control.

What is a two-stage thermostat?

In its simplest form, a thermostat is a switch that activates at a certain temperature. The temperature (setpoint) is usually adjustable, and, for heating, the switch contacts typically close as the local temperature drops (a.k.a. "open on rise"). A closed switch is the most common signal used as the "call for heat" in any heating control system. An ordinary thermostat with one setpoint (and one switch) may also be called a single-stage thermostat. A two-stage thermostat is one that contains two single-stage thermostats in one unit, where the two setpoints are linked together.

Differential and dead band

Every common thermostat has a differential built into it. Most people assume that their thermostat turns on and off at the setpoint temperature that they choose. This is not exactly true. The setpoint temperature establishes a target for the heating system. The thermostat then turns on and off, cycling the heating system above and below the target temperature. It is not unusual for a common room thermostat to allow the room temperature to fluctuate above and below the setpoint by one or two degrees (F). This total fluctuation (e.g., 2 to 4 degrees F) is known as the differential, defined as the difference between the highest and lowest temperature allowed by the thermostat as it is seeking its target.

Two-stage and other multi purpose thermostats also may have a "dead band" built into them. This is a range of temperature where literally nothing happens. There is no call for heating (or cooling) because the local temperature is between the chosen setpoints and outside of the range of the differentials.

The most common two-stage thermostats have few adjustments and provide a factory-set differential. If you shop around and compare features, you can find thermostats with not only the high limit and low limit setpoints adjustable but also the high and low differential and dead band (if included) may be adjustable, too. The adjustable models are more easily adaptable to direct-solar heat storage requirements, as I will explain below.

Solar differential heat control

The most common solar control is the solar differential thermostat, which is most often used to control the heat stored in a tank of hot water. A *differential* is a difference between two temperatures. As I mentioned above, for a room thermostat the differential is the difference between the lower temperature at which the heating system turns on and the higher temperature at which the heat turns off. A solar differential is typically the difference between the hot solar supply temperature and the cooler heating load

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(e.g., the hot water tank). So, a solar differential control always has a minimum of two temperature sensors, a way of comparing them and a switch that activates only when the hot (solar) sensor is positively hotter than the cool (storage) sensor.

In the early days of active solar controls, this was done with capillary tube sensors and thermo-mechanical switches. These days, virtually all solar differential controllers are built around integrated circuits using thermistor sensors and include other useful functions, such as high limit control. This is an important feature that can be used to prevent a solar heated tank or other heat storage system from getting too hot when the solar heat is not being consumed. It can also be used to activate a cooling mechanism to remove heat from a storage system that has become too hot (before the P&T valve blows off).

A solar differential control with a high limit control is another version of a two-stage thermostat. It turns on and off in response to low limit conditions in the storage tank, defined by the programming of the two temperature sen-

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sors. The low limit setpoint is a moving target, changing as the difference between the two temperature sensors changes. The high limit control provides a second stage that activates cooling or, at a minimum, provides a heating dead band when things are getting too hot.

Solar heat storage mass

Many common materials can be used to store solar heat, simply by raising their temperature. In the solar heating world, this is commonly referred to as *thermal mass*. Water is the most common solar heat storage material, storing one Btu per pound of water for every degree (F) of temperature rise. In fact, this is the definition of the Btu (British thermal unit). Concrete (and any high density masonry material) can also be used to store solar heat, although it absorbs less than half of the heat that water does, given the same volume at the same temperatures. Still, there is a large volume of concrete in every warm concrete floor that can be used as solar heat storage from day to day, and we have found this abundant source of thermal mass to be very useful.

Two-stage heat control

In our region, over the past decade or so, we have been installing increasing numbers of active solar heating systems that are solar-direct hydronic radiant-heated mass floors. A solar-direct system allows the solar heat to flow directly from the solar collector into the mass floor. It is not diverted or delayed in a water storage tank or other indirect heat storage system on its way to the mass floor. In this way, we eliminate the heat loss and temperature drop associated with time spent in remote storage, delivering more heat per square foot of solar collector to the heating load. Since the mass floor is within the comfort zone of the living space, it is important to control the temperature of the floor to allow for solar heat storage without overheating that zone of the house. We have been using two-stage room thermostats for this purpose.

These thermostats are often called heat pump thermostats, because they are typically used to control air-source heat pump heating systems. Air-source heat pumps operate most effectively when the outdoor air is well above freezing. When the heat pump cannot keep up with the heating load during freezing weather, an electric resistance heating system makes up the difference. So, a two-stage thermostat is used to maintain the room temperature at a slightly higher setpoint with the heat pump, and, as the room temperature drops one or two degrees, a second stage fires up the electric resistance heat.

Solar-direct two-stage heat distribution

Although our climate in Santa Fe is too cold in winter for air-source heat pumps, we use the same principle to control solar-direct heat. The low limit setpoint is used to boost the room temperature to a minimum comfort temperature using a hydronic backup boiler if the solar heat cannot keep up. The high limit setpoint is then wired to a solar control (typically a solar differential) and waits until solar heat is available. It then delivers solar heat to the thermal mass of the floor until the room temperature reaches the limit of the upper differential temperature range. By raising the temperature of the mass floor just one degree (F), we have stored thousands of Btu in the thermal mass, which will radiate out into the room over a period of many hours, delaying the boiler from turning on.

In this way we are putting the "thermal flywheel" effect of the mass floor to good use by prolonging the delivery of solar heat well into the evening. The backup boiler will not fire until the room thermostat drops all the way through its high-limit differential range. This is why it is good to have programmable room thermostats that allow you to change the high limit differential. The more you allow the room temperature to fluctuate above and below the high limit setpoint, the more solar heat you can store and release in the thermal mass of the floor.

The final settings depend entirely on the comfort preferences of the occupants. I have found most people can accept a four to six degree (F) gradual room temperature fluctuation without complaint, especially when they know that the warmer temperatures are provided by solar heat. In larger houses with ample thermal mass in the floors, we only allow the rooms to fluctuate by two to three degrees so that the warmer rooms will reach their high limit sooner, allowing the cooler rooms to get more of the solar heat distribution. In this way, solar heat is dispersed around the house evenly into all the floors, controlled by the high limit setpoint on each room thermostat. Since two-stage room thermostats are invisible to the user, owners can operate the system without any special training. They turn the room temperature up and down in the normal way, and the internal setpoints and differentials take care of themselves after the installer programs them.

Control systems are evolving

This article describes some of the simplest thermostat switches that are in common use in existing heat control systems. Newer control systems are beginning to move away from simple switches and more into thermistor sensors, digital logic, variable temperature response capabilities and even remote network accessibility. The design principles of RELIABILITY, COMPATIBILITY and ELEGANCE remind us that, in some applications, maybe all you need is a switch. If so, simpler is better. At Cedar Mountain Solar we are always working on that fine balance between providing better controls while keeping them as simple to use as possible. Our control systems will be incorporating new technologies and control strategies as they evolve and prove themselves worthy of the Six Principles. ■

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