Refrigerator Thermostat Cool-off

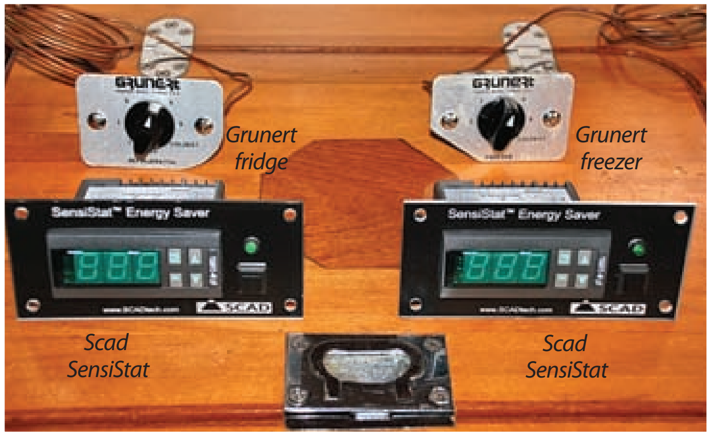
Is a digital control system worth the extra expense?

In the dark ages of marine refrigeration—about 30 or 40 years ago—a timer or simple switch was used to activate the electric clutch of an engine-driven automotive air-conditioning compressor until a holding plate in the refrigerator box was completely frozen. When the holding plate had thawed to the point where it could no longer keep the compartment cool, the cycle began again. With some experimenting, a cruising sailor could learn to operate this type of system fairly efficiently.

Modern marine refrigeration installations have moved far beyond this simple, but still viable approach. Holding-plate systems now compete in a market where less expensive and more easily installed evaporative systems have become commonplace. (An upcoming article in *Practical Sailor* will compare the latest 12-volt evaporative systems.)

In either system the thermostat can hold the key to efficiency, although how it functions in each is quite different. In an evaporative system, a refrigerant is circulated through the insulated box, removing heat with each circuit. To maintain the proper temperature, the cooling cycle is repeated at fairly frequent intervals. The thermostat in the evaporative system is tasked with monitoring the box temperature, starting the system at a preset level, and stopping it when the compartment is cooled sufficiently.

In a holding-plate arrangement, the tubing of an evaporative system is replaced by a grid of refrigerant tubing immersed in a eutectic solution. To cool the box, the system compressor must be run until the holding plate is completely frozen. Then, over a period of several hours, the holding plate absorbs heat from the compartment until it thaws, and the compressor must be restarted to repeat the cycle. Compared to evaporative systems, the holding plate behaves more like an ice block, capable of maintaining a cool box for longer periods when power is unavailable.



The SensiStat digital thermostat is physically larger than the Grunert mechanical types, but the sensor wires are easier to install than capillary tubing.

In the holding-plate system, the thermostat cannot directly control the compartment's temperature. Instead, it plays a two-part role in determining holding plate efficiency. First, it must decide when the eutectic solution is frozen. Then, at the opposite end of the sequence, the thermostat must determine when the holding plate has thawed to a point at which it can no longer adequately absorb heat.

At either point of the cycle, if the thermostat waits too long to start or stop the compressor, the compressor runs more often than is needed, reducing efficiency.

The SensiStat connections are made individually at labeled terminals. Sensor wires are color coded. Any installations will need external strain relief clips for the wires.

For many years, refrigeration thermostats have consisted of a metal capillary tube (usually copper) connected to a diaphragm in the thermostat housing. When the sensor or bulb at the end of the capillary tube is placed on the holding plate's surface, a change in temperature leads to a change in pressure that moves the diaphragm. The diaphragm movement activates a switch, which, in turn, starts and stops the refrigeration compressor. Often referred to as mechanical thermostats, they don't require electrical power to function and the reference temperature or "setpoint" is adjustable. Some delay or hysteresis is incorporated into the switch design to prevent rapid cycling of the switch near the setpoint. Typically, this differential temperature range is about 10 degrees. but some mechanical thermostats can be adjusted to alter the range.

In more recent times, digital technology has migrated to thermostats. Not only do these devices bring the convenience of a digital display, but they feature an almost infinite adjustment of the setpoint and the differential temperature. Like its mechanical counterpart, the digital thermostat controls the operation of

Testers measured voltage and current at a shunt in the refrigeration system's negative lead and logged it on a laptop at one-second intervals.

the refrigeration system components with a built-in switch but it also requires electrical power to operate. These devices often use a thermistor (a device whose resistance varies with temperature) or thermocouple (a device that generates current proportional to the heat it is exposed to) to translate temperature changes into electrical current that controls the thermostat. The mechanical thermostats are touted for their reliability, low cost, and ability to function without electrical power. Advocates of digital thermostats claim better accuracy, versatility, and efficiency.

After many years of experience with Grunert mechanical thermostats that are fairly representative of the traditional mechanical thermostat, we decided to put them up against the SensiStat, a modern digital thermostat offered by Scad Technologies. Although a digital thermostat offers some benefits for evaporative system, the most significant efficiency gains would be expected with holding plate systems.

The Scad retails for more than three times the Grunert, so there were many questions that needed to be addressed. Would a digital thermostat improve efficiency enough to produce a noticeable savings in energy? Did the claims for greater convenience and versatility really justify the added expense? What about the installation itself?

WHAT WE TESTED

Since the test included both fridge and freezer comparisons, we used two Grunert mechanical capillary refrigeration thermostats, one for the fridge (#A30-544/72, $70) and one for the freezer (#A30-2290-00, $67). The 72-inch capillary tubes on each of these units is long enough to allow remote mounting. The controls include an off position and an uncalibrated range of settings indicated by the numbers 1 through 6. The thermostats cannot be used interchangeably to control a freezer or a refrigerator system, but they don't require electrical power to function.

Our digital sensor and display was the new SensiStat developed by Scad ($300). The device requires 12- or 24-volt power supply and automatically determines the supply voltage. An automatic compressor protection creates a minimum delay of 5 minutes between compressor runs. Thirty seconds after battery charging is detected, the unit enters a "Free Power" mode that changes the pre-programmed differential temperature to 1 degree. This starts the refrigeration system to take advantage of the extra power available from the alternator. A user-activated manual override mode changes the pre-programmed differential temperature to 1 degree for 60 minutes for extra freezing time, if needed.

The manual override mode can be canceled, and "Free Power" mode can be disabled, if desired. Either the compartment or the plate temperature can be displayed continuously. The other can be momentarily displayed when desired. Supply voltage is monitored, and an over-voltage condition will prevent the refrigeration system from running until it is corrected.

An LED indicates when the SensiStat is requesting the refrigeration system to run while another LED indicates the current mode and provides feedback when programming some parameters.

Various parameters can be adjusted to allow the SensiStat to be used with either a freezer or refrigerator. The following parameters can be programmed by the user:

- Setpoint temperature.
- Differential temperature range.
- Differential temperature range used by "Free Power" and override modes.
- Displayed temperature in Fahrenheit or Celsius.
- Voltage level used to detect engine alternator output.

HOW WE TESTED

The test system consisted of a separate freezer and refrigerator, each regulated by separate thermostats that control a common system compressor but separate solenoids valves. The valves only allowed refrigerant to enter the holding plates of the compartment that each thermostat was controlling. System parameters were monitored with a Dickson Temperature Chart recorder with the probe mounted on the holding plate in the compartment being monitored. Voltage, amp/hrs. and time were monitored with data recorded once per second by computer.

The evaluation was conducted by first recording the performance of both the freezer and refrigerator for several days with the Grunert mechanical thermostats installed. Data was recorded at several different thermostat settings, and then the procedure was repeated with the SensiStat digital thermostats installed. Care was taken to place

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PS VALUE GUIDE GRUNERT vs. SCAD THERMOSTAT FREEZER

DEVICE	PRICE/SOURCE	BASIS	SETPOINT	DIFFERENTIAL	HOLDOVER TIME	CYCLE RUN TIME	ENERGY PER CYCLE	ENERGY/ 24 HOURS
GRUNERT A30-2290-00	$70/ Marine Air	Optimum	0˚ F	10˚ F	6.3 hrs.	34 min.	13.8 amp/hrs.	48.2 amp/hrs.
		Coldest	-5˚ F	5˚ F	3.7 hrs.	50 min.	17.6 amp/hrs.	93.2 amp/hrs.
SCAD SENSISTAT	$300/Scad	Default	0˚ F	8˚ F	3.9 hrs.	30 min.	10.3 amp/hrs.	56.2 amp/hrs.
		Optimum	-5˚ F	15˚ F	11.2 hrs.	66 min.	24.1 amp/hrs.	47 amp/hrs.

Freezer comparison shows similar energy needs

By experimenting, we were able to achieve optimum freezer settings for the set point and differential for each of the freezer thermostats. A setpoint higher than the optimum tended to allow the freezer compartment to get too warm. The holding plate specifications call for a lower setpoint, but the differential on the Grunert thermostat is not adjustable. It is determined by the hysteresis (built-in delay) of the thermostat, and this delay period also decreases when the setpoint is adjusted lower. This, in turn, reduces the holdover time, resulting in more frequent cycling of the system and less efficiency. The optimum setting produced the most efficient operation with acceptable freezer compartment temperature and was at approximately the mid-point in the Grunert's control's range.

The SensiStat factory default values for setpoint and differential are 0 degrees and 8 degrees, respectively. As we found through testing, though, these values may not be the most efficient. Compared to the Grunert thermostat freezer performance, the SensiStat didn't save a remarkable amount of energy at our optimum settings, but the average freezer temperature was 2.5 degrees less, and this can be significant.

PS VALUE GUIDE GRUNERT vs. SCAD THERMOSTAT FRIDGE

DEVICE	PRICE/SOURCE	BASIS	SETPOINT	DIFFERENTIAL	HOLDOVER TIME	CYCLE RUN TIME	ENERGY PER CYCLE	ENERGY/24 HOURS
GRUNERT A30-544/72	$70/ Marine Air	Optimum	16˚ F	11˚ F	11.4 hrs.	28 min.	11.4 amp/hrs.	23.1 amp/hrs.
		Desired	18˚ F	10˚ F	24+ hrs.	NA	NA	NA
SCAD SENSISTAT	$300/ Scad	Default	18˚ F	8˚ F	6.4 hrs.	14 min.	6.4 amp/hrs.	23.2 amp/hrs.
		Optimum	18˚ F	10˚ F	23.9 hrs.	30 min.	12.8 amp/hrs.	12.6 amp/hrs.

Finding the optimum set point for fridge control

The operation of the test fridge has been problematic for several years. The single holding plate has excellent eutectic characteristics and will hold a stable surface temperature of near 28 degrees for many hours. Typical of any eutectic solution, the temperature would rise rather quickly after it was thawed, and this troubled the mechanical thermostat. With hysteresis set by the internal workings of the switch, the thermostat was frequently unable to detect the end of the thaw cycle until it was too late. Settings near the desired position gave inconsistent results. As a compromise, the thermostat was to set low enough so that it always started the freezing cycle before this could happen. The optimum figures in the table reflect this compromise, but it was almost impossible to know what the true optimum settings would be for the mechanical thermostat.

The SensiStat default setpoint of 0 degrees is for a freezer, but experimentation seemed to indicate that 18 degrees was about right for the refrigerator cold plate. The factory-default differential of 8 degrees was retained, and this provided some interesting results when contrasted with what were ultimately determined to be the optimum settings. The differential settings for the Scad in the table above clearly shows the difference a degree or two in a set point can make in terms of efficiency. The refrigerator plate temperature rose to 26 degrees in a few hours and then took almost 18 more hours to rise above 28 degrees. Cycling the plate below its eutectic range is quite costly in terms of efficiency. The SensiStat was consistent at the upper end of the differential range, and excessive thawing has not occurred with these settings, even after an additional two weeks of observation.

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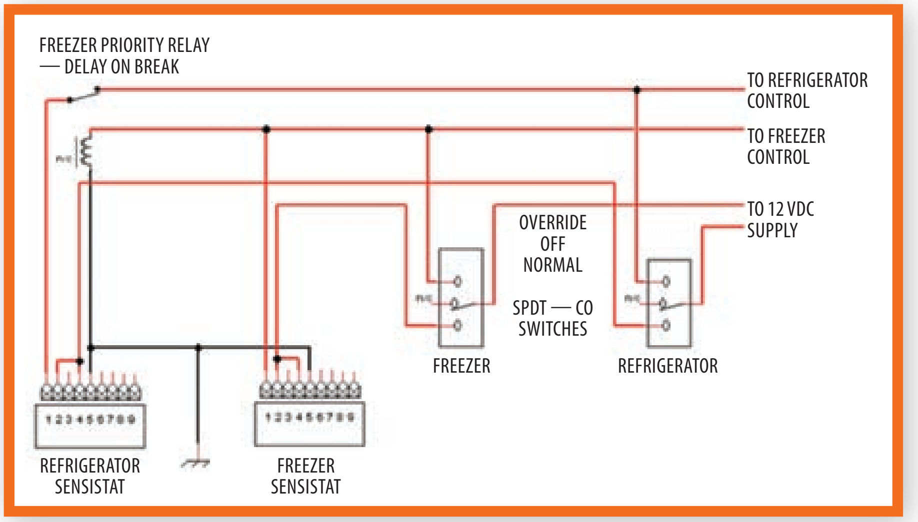
the probes or sensors for both types of thermostats at the same location on the plates as recommended by the holding plate manufacturer. Both the refrigerator and freezer compartments were filled to 75 percent of capacity with typical food items and sealed. The temperature was allowed to stabilize before data recording began. The average air temperature outside the compartments was 86 degrees.



The SensiStat does not include a method of temporarily preventing the refrigeration system from running. To fix this, we'd recommend adding SPDT switches for the fridge and freezer. Each switch would have three settings, one for normal thermostat operation, one for bypassing the thermostat to manually start the compressor (chill), and one to cut off power to the thermostat to prevent it from starting the system (thaw). Also, to maximize efficiency when the cold plates in both the fridge and freezer need to be frozen, we'd include a relay that prevents simultaneous freezing of all cold plates, giving the freezer priority.

WHAT WE FOUND

The "Free Power" mode did a nice job of detecting engine operation when the alternator began to charge. Cruisers have been doing this manually for years, but the SensiStat won't forget to reset the system after the anchor is down.

There may be some unexpected consequences of this feature. Solar panel or wind charger output may trigger this mode if the batteries are fully charged, or it may be activated by a momentary interruption in shore power, if this causes the charger to leave the float mode. You can program the voltages for activating and terminating the "Free Power" mode and can also set the differential temperature referenced while in this mode. It is possible to disable the "Free Power" mode when shore power is connected for extended periods, which would be a good idea. Some of the instructions for making these settings could be better.

It would also be better if the SensiStat included a connection for a high temperature alarm, a welcome addition to any installation.

Digital monitoring of the refrigerator or freezer compartment temperature is a nice feature and a good tool for making adjustments, but a significant amount of temperature stratification may exist, especially in the freezer. Locating this sensor near the compartment center vertically is probably the best choice, but the coldest area will still be at the bottom of the compartment.

The manual override mode works as advertised and did a good job of shortening the amount of time it took to freeze new items in the freezer. Unless you cancel the mode, it will hold the cold plate within 1 degree of the setpoint for 60 minutes.

CONCLUSIONS

Directions for installing the SensiStat sensors and display are well documented and easy to follow. The display is designed to be panel-mounted externally where it can be easily monitored. Sensor wires (unlike capillary tubes) can be extended as needed. Retrofitting is also straightforward, though you might have to add a ground wire at the thermostat location.

Mechanical thermostats are valued for their simplicity and reliability, but a digital thermostat may often outperform it when it comes to maximizing system performance. The accuracy and repeatability of temperature measurements (within .10 of a degree for the SensiStat) delivered by a digital thermostat certainly contributes to efficiency, but its biggest asset may be its ease of use and versatility. The SensiStat was notably better than the mechanical thermostat when it came to getting the most out of the system, but the setpoint and differential temperatures should be mapped to the characteristics of your holding plates. The default settings may not be the best option.

From a performance standpoint, the digital thermostat would seem to be the clear winner here. Reliability remains to be seen, but readers have reported good customer support from Scad for its other products. Based on the SensiStat's performance during testing, it would be a good choice when considering a digital thermostat.

Compared to a mechanical thermostat, the SensiStat is not cheap, but we expect the prices for digital sensors to come down as the technology takes hold.

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