A photograph of a classroom interior. Rows of yellow desks and chairs are arranged facing forward. Large windows on the left wall let in natural light. A black chalkboard is mounted on the right wall. The background features a colorful, abstract graphic overlay with red, orange, and blue hues, along with white horizontal lines.

Using Control Charts to Monitor **ROOM TEMPERA**



by Albena Ivanova
and Scott Albert

In 2009, Slippery Rock University in Pennsylvania installed a new Building Automation System (BAS) to monitor and control the room temperatures. The system takes temperature readings in multiple spaces. When the outside temperature rises above 60 degrees, the air-conditioning mode is activated. When the outside temperature drops below 50 degrees, the heating mode is activated. When the outside temperature is between 50 and 60 degrees, the system is in “neutral” mode. Even though the system allows predetermined setpoints, the actual temperatures in many spaces was much lower or much higher than the setpoints.

The Case of Slippery Rock University

The university was incurring high heating/cooling costs due to lack of control in the building HVAC systems. This project aimed to determine whether the space temperatures were in control and to identify ways to avoid unnecessary heating or air-conditioning costs.

DATA COLLECTION AND ANALYSIS

The project started by visually inspecting all spaces, taking pictures of the factors affecting the temperature, and recording users' satisfaction with the room temperature. BAS contained historical data on the daily temperature readings, taken every 15 minutes for 12 months. BAS also contained the individual spaces current setpoints used as specification limits. For example, if a room setpoint was 72 degrees F, the specification limits were 72 ± 2 degrees, resulting in lower specification limit (LSL) of 70 degrees F and upper specification limit (USL) of 74 degrees F. Figures 1 and 2 represent the s-chart (daily standard deviation) and the \bar{x} -chart (daily average) for the Choral Room June temperature.

Next, we computed the process capability indexes revealing if the process is capable of meeting the specifications.

RESULTS

Analysis reveals several situations:

Process in-control and capable (~2% of the cases). No need for change.

- *Process in-control but not capable (~13%).* Look at Choral room (Figures 1, 2, and 3). Two options exist: reduce the process standard devia-



tion, and revise the specification limits. In the Choral room case, revision of the limits is a preferable solution, as this will not affect the customer satisfaction. The Choral room is spacious and used by many people. If the tolerance is increased from 2 to 3 degrees, the process will be almost capable ($C_p = 0.91$, $C_{pk} = 0.84$) and with higher customer satisfaction.

- **Process out-of-control due to identifiable special cause (~49%).** The process is out of control due to three main causes: turning the HVAC system off during the weekends; turning it off during the holidays; and high variability in external temperature. Figures 4 and 5 illustrate the situation when the temperatures go above the upper control limit every seventh day. In July, the facility turns the air-conditioning units off for the weekend, as the classroom is unused. The weekend readings during unoccupied times should be removed from the analysis and new control limits calculated.

Figures 6 and 7 illustrate similar situations with average temperatures on January 1, 2, and 3 way below the lower control limit.

Figure 1. Daily standard deviation (s-chart) of the Choral Room June temperature

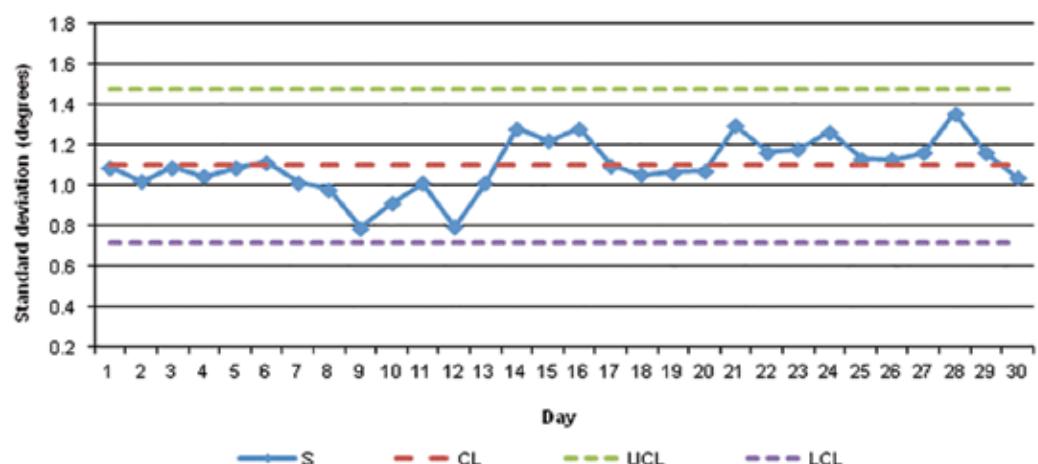


Figure 2. Daily averages (\bar{x} -chart) of the Choral Room June temperature

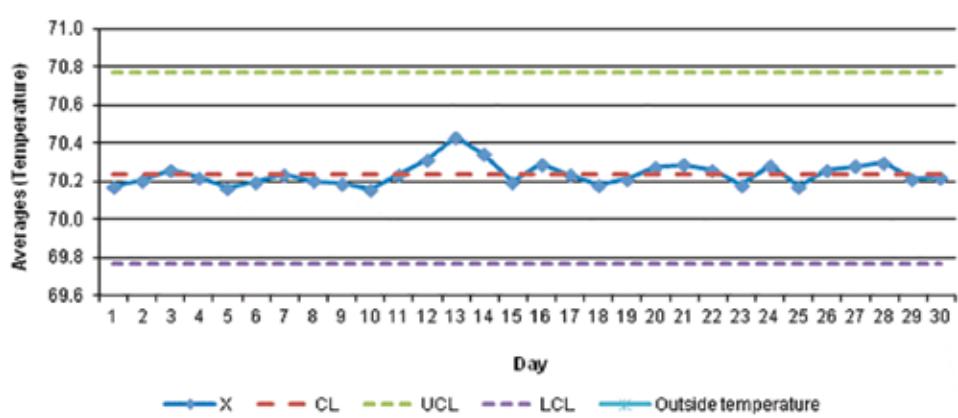


Figure 3: Process Capability of the Choral Room June temperature

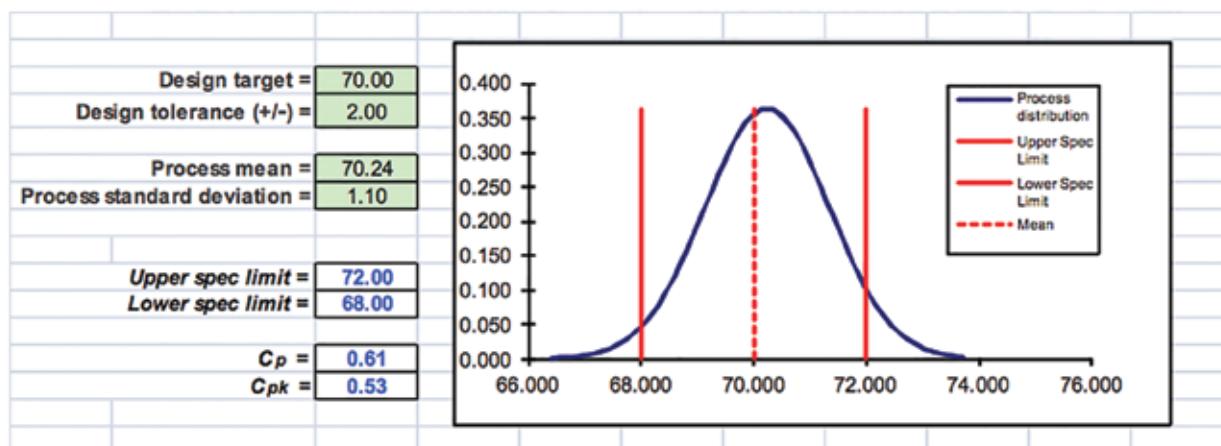




Figure 4. Daily standard deviation (s-chart) of the Classroom July temperature

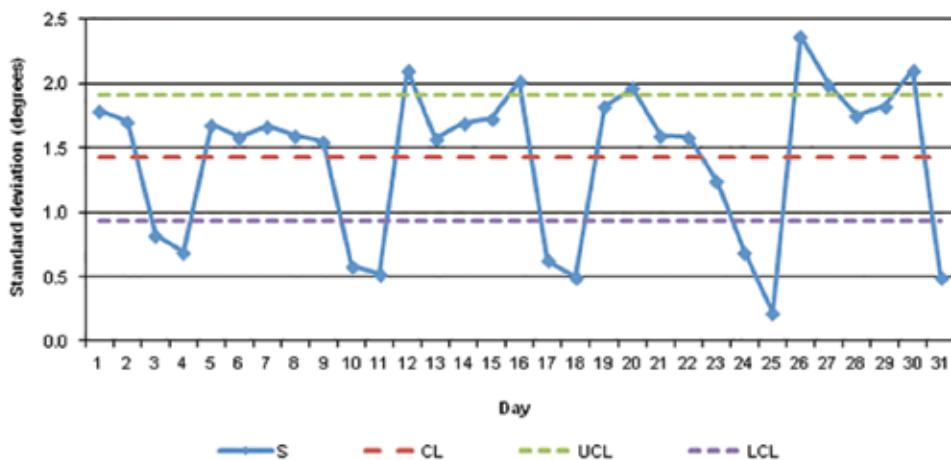


Figure 5. Daily averages (\bar{x} -chart) of the Classroom July temperature

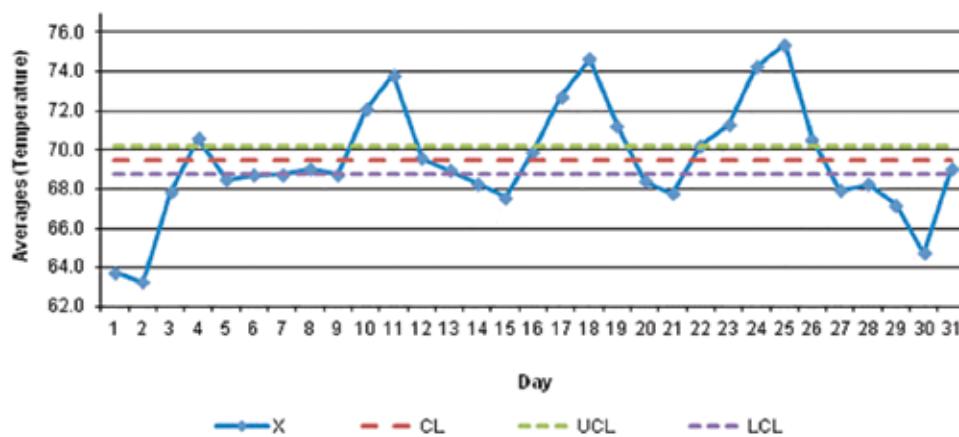
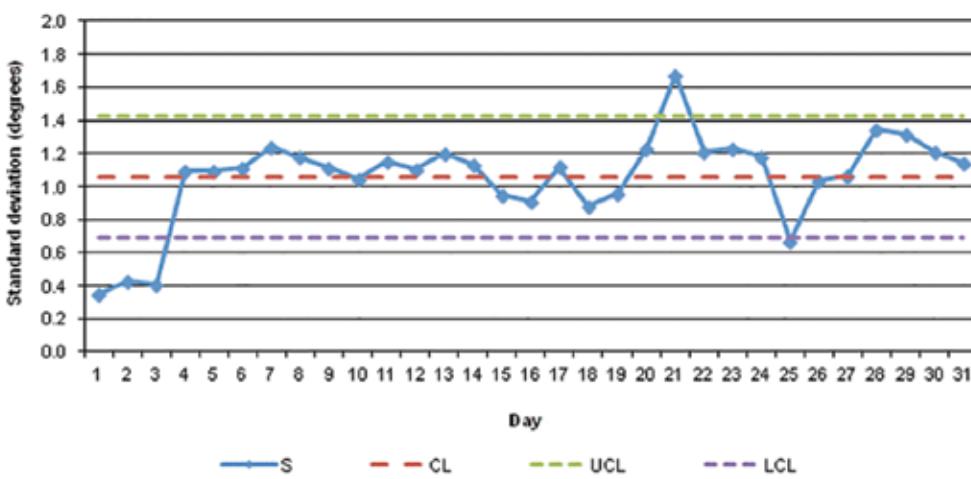


Figure 6. Daily standard deviation (s-chart) of the Alumni House January temperature



During these days, the university was closed for the winter break and the heating was turned off. These three-day readings should be removed from the analysis and new control limits calculated.

Figures 8 and 9 present a situation where the temperatures are out-of-control due to rapid changes in the outside temperature, usually during the spring and fall months. One may argue that the outside temperature is not a special cause, as the goal of the heating/air-conditioning is to keep the inside temperature constant despite the outside temperature amplitudes. Internal and external temperatures, however, are highly correlated. That is why high external temperature amplitudes are a special cause.

Adjusting the process during these months is difficult, as the heating/air-conditioning units are set up to respond to the changes in external temperature. The situation is even more complicated when the system transitions back and forth between heating and cooling modes.

- *Process out-of-control due to unidentifiable special cause (~36%).* Figures 8 and 9 illustrate that the Auditorium November out-of-control temperatures are not related to the outside temperatures. Management needs to investigate and correct the problem. Common problems include power outages (requiring restarting the variable frequency drives controlling the air-handling unit fan motors) or building air compressor (provides control air) failure.

Approximately, in 85 percent of the cases the temperature was out-of-control. In three spaces, room temperatures were higher than the setpoints. In one space, temperatures were lower than the setpoint. In four spaces, temperatures were outside the specification limits.

The winter break, with the HVAC



systems turned off, forced the January room temperatures out-of-control. High outside temperature fluctuations forced April and May room temperatures out-of-control. The cooling/heating modes come from the same system but are activated depending on the outside temperature. High outside temperature fluctuations cause high inside temperature fluctuations as the system goes back and forth from cooling to heating mode. Similarly, in June, high outside temperature fluctuations and the HVAC system off during the weekends lead the process out-of-control (above the upper control limit).

In July, the air-conditioning is turned off during the weekends, resulting in out-of-control temperatures (above and below the control limits). In August, low occupancy and HVAC system turned off at different times, forced temperatures out-of-control. In September, when the classes resume, the temperatures go out-of-control due to the system adjusting to the weather changes. In October, the temper-

Figure 7. Daily averages (\bar{x} -chart) of the Alumni House January temperature

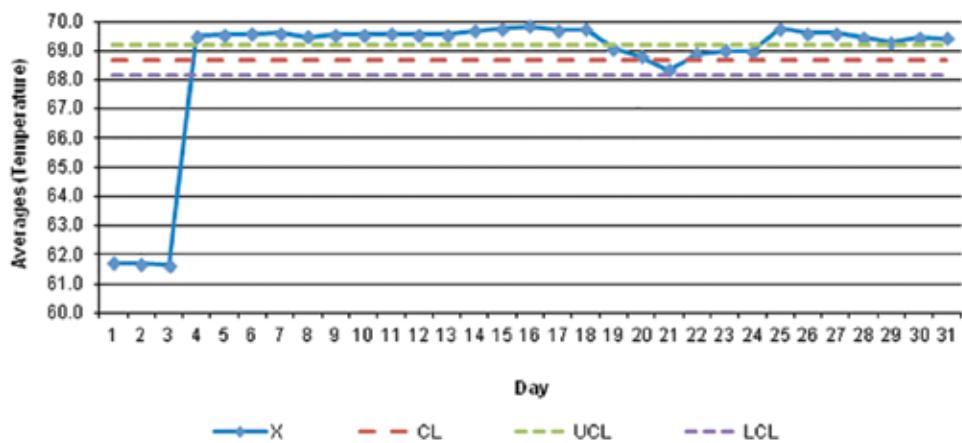


Figure 8. Daily standard deviation (s-chart) of the Band Room May temperature

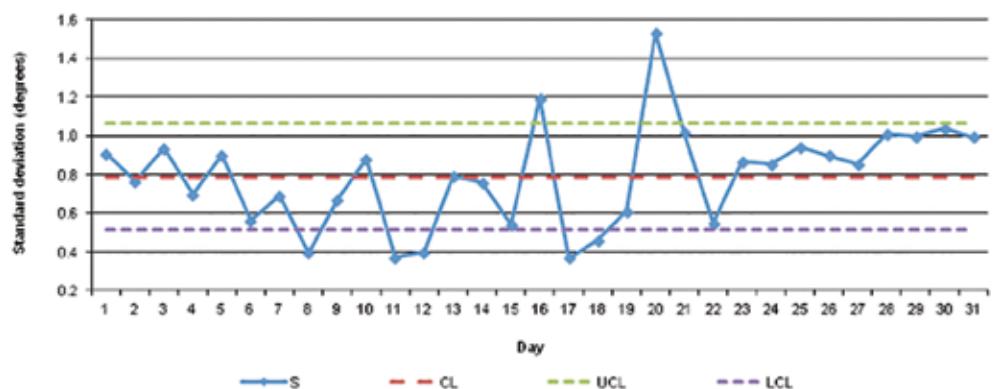


Figure 9. Daily averages (\bar{x} -chart) of the Band Room May temperature (outside temperature readings are listed on the second axis)

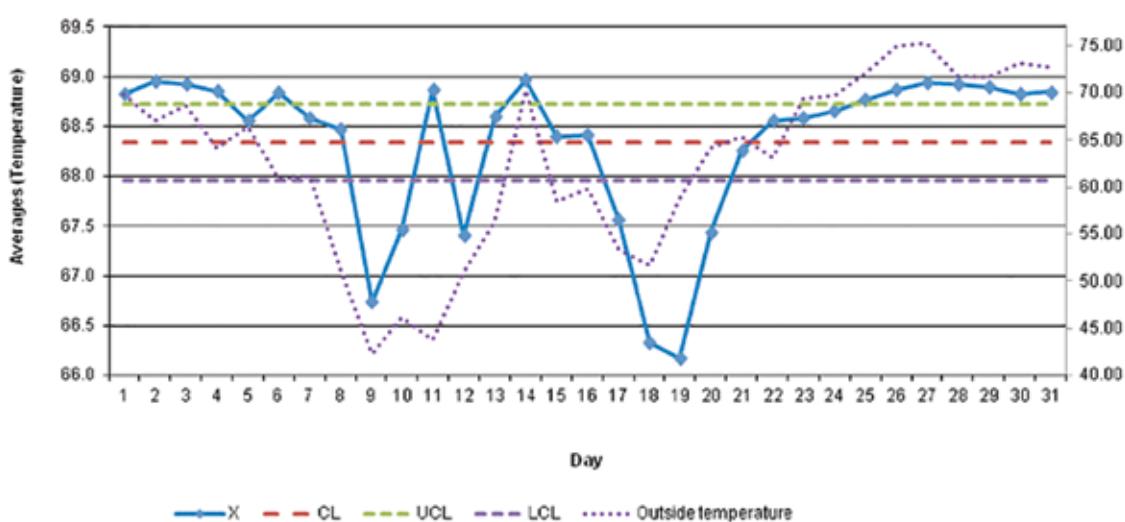


Figure 10. Daily standard deviation (s-chart) of the Auditorium November temperature

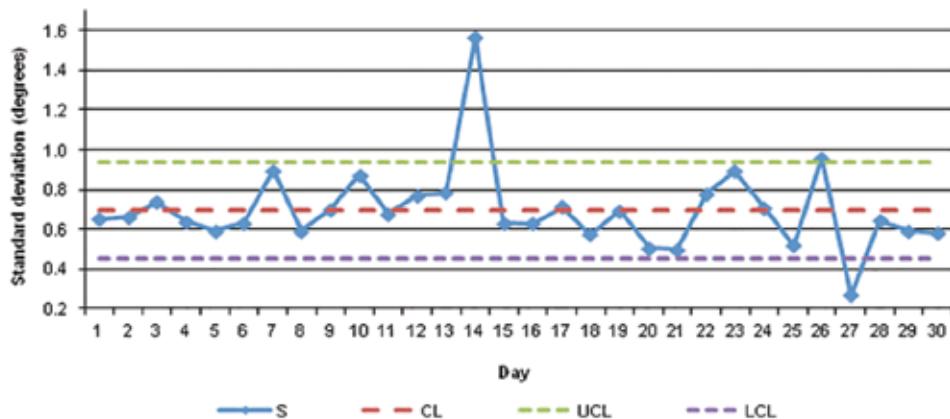
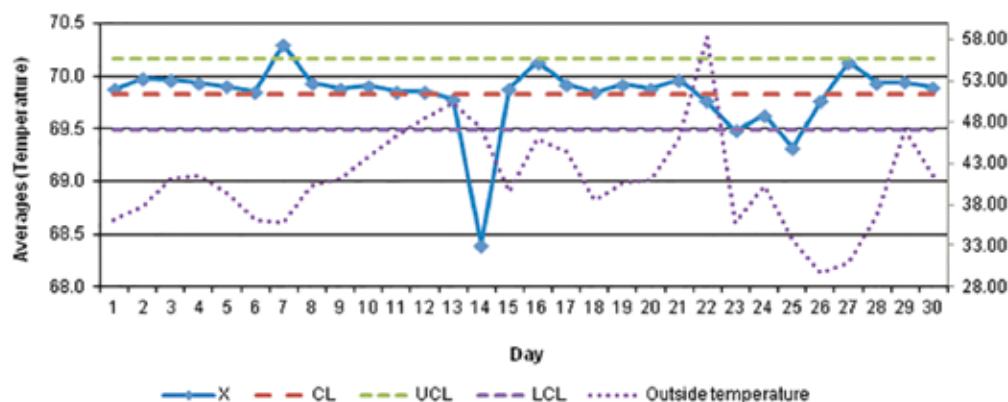


Figure 11. Daily averages (\bar{x} -chart) of the Auditorium November temperature (outside temperature readings are listed on the second axis)



tures are out-of-control and much lower than the setpoint. In November, the temperatures are out-of-control and much higher than the setpoint. In December, the temperature is again out-of-control, due to turning off the heating during the weekends.

RECOMMENDATIONS

Based on the analysis, we made the following recommendations:

A. Process standardization. The setpoint for the Meeting room 1 was 74 degrees and for Meeting room 2 was 70 degrees. The more consistent the setpoints, the easier the process control.

B. Tolerances. Many of the control charts were out-of-control, much higher or lower than the specification limits, because of the narrow specifications limits. When the specification limits are set with one-degree tolerance (Auditorium and Classroom), increase the tolerance from one to two degrees. Small increase in the tolerance, irrelevant to the customer, will make the process capable.

C. Process mean higher than the specification target. When the process mean is higher than the specification target, reset the setpoint. For example, Library reading room temperature was consistently much higher than the setpoint of 72 degrees. It is a closed space, with no windows, with computers and a printer constantly in use, generating a lot of heat, making the space hot and uncomfortable to use. Reducing the setpoint to 70-68 degrees will partially solve the problem, as the heat around the space during the heating season is enough.

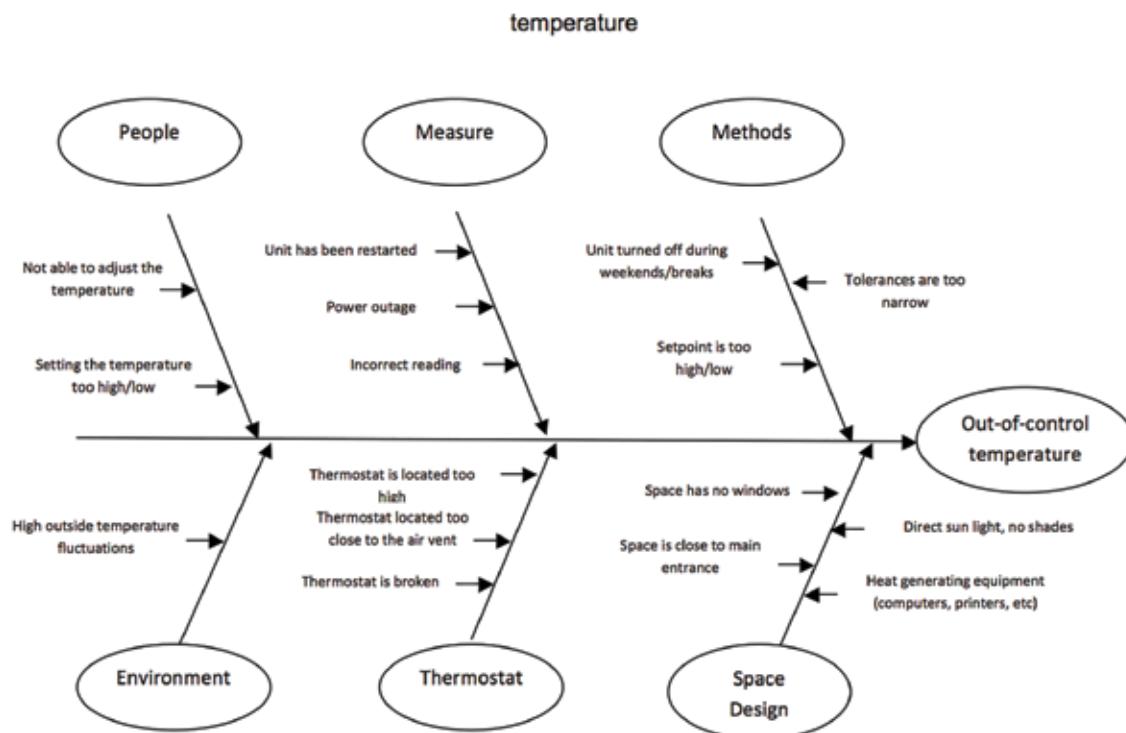
D. Process mean lower than the specification target. Similarly, for those spaces where the process mean is lower than the specification target, the setpoint could be reset based upon occupancy. Meeting room 1 had temperatures much lower than the specification limit, especially during the summer months. The setpoint was 74 degrees, but the room was kept much colder with the air-conditioning running at full power, even when the space was not in use. Similarly, the Classroom was

not in use during May, June, July, and August but had a cooling setpoint of 70 degrees. In this particular case, the university is wasting money cooling an unused space. Either reset the setpoint to higher temperature, based upon room occupancy, or turn the unit off when the space is not in use. Shade the windows to block the sun during the summer months.

E. Redesigning spaces. Cafeteria is a large space, with an automatic door at the main entrance. The door is constantly open as people go in and out. Outside temperature impacts inside temperature, making the place cooler in winter months (December) and warmer in summer/fall months (June, July, August, September, and November). Employees are using individual electric heaters to stay warm during winter months, causing higher inside temperature fluctuations and incurring additional costs. One possible solution is installing an air curtain serving as a shield against the cold blast coming in through the doors. Solution that is more expensive



Figure 12. Cause-and-effect diagram (Fishbone) for the causes of out-of-control temperature



is redesigning the exterior entrance so the west wind is not entering the lobby when people enter the building. Placing window shades will also reduce the sun impact and improve the temperature control during the summer months. Similarly, Meeting room 2 is exposed to outside airflow through the entrance doors, resulting in the process being out-of-control all the time. Adding a second set of doors could improve the temperature control in this space.

F. *Allowing users to adjust the temperature.* In several spaces, the thermostats were either broken (Classroom) or deliberately removed (Meeting room 1) to limit the users control over the temperature. The idea was to prevent people adjusting the setting and interfering with the room temperature control. Allowing the Classroom users to reduce the temperature in November, however, would have saved the university money on heating.

G. *Consider the thermostat location.* The thermostat location tremendously affects the readings. For example, the Library reading room thermostat is located directly under the air vent. The Alumni house offices thermostat is located high on a wall picking up the warmer air in the room, resulting in readings that are higher than the temperature that people actually feel in the room. When not practical to change the thermostat location, consider it when determining the room setpoints.

Finally, to illustrate better the causes of the out-of-control temperatures, a cause-and-effect (Fishbone) diagram is presented on Figure 12. The causes are classified in different categories:

People, Measures, Methods, Environment, Thermostat, and Space Design. It may not be possible to control the outside temperature (Environment) or to change the Space Design, but the rest of the categories provide opportunities to improve room temperature control.

CONCLUSION

The fact that most of the charts were out of control requires reevaluation of the factors affecting room temperatures, process standardization, and redefining the setpoints and tolerances of the system. Given the complex nature of the task and the numerous factors impacting room temperature, it is advisable to first evaluate common spaces and to reevaluate them annually to reflect any changes in usage and space design. As this was the first time the facility analyzed temperature readings, the study became a pilot one for further analysis.

Monitoring room temperatures provides useful insight into the process and identifies ways to improve customer satisfaction and save money at the same time. We believe that the methodology of the analysis and the results could be used by other facilities at different institutions. ☺

Albena Ivanova is an associate professor in operations management at Robert Morris University, Moon Township, PA; she can be reached at albena.iossifova@gmail.com. Scott Albert is director of facilities at Slippery Rock University, Slippery Rock, PA; he can be reached at scott.albert@sru.edu. A longer version of this article first appeared on *Engineered System's* website at www.esmagazine.com.



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