TECHNICAL FEATURE

Demand-Controlled Ventilation For Commercial Kitchens

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Food service facilities have high energy consumption with equipment and commercial kitchen ventilation (CKV) being the primary energy consumers in a restaurant. Exhaust hood airflow drives HVAC energy consumption for CKV, so the first step in reducing this exhaust airflow is designing high efficiency hoods with low capture and containment (C&C) airflow rates. The next step is using demand control ventilation (DCV) to further reduce exhaust airflow when cooking is not taking place under the hood, but when appliances are hot and ready for food preparation.

Airflow reduction is not the sole objective of a DCV system; it also must ensure exhaust airflow and the corresponding supply airflows are increased to C&C levels as soon as cooking starts (to avoid spillage of convective heat and cooking effluent into the kitchen space). The current NFPA-96 Standard[1] and International Mechanical Code[2] require that a hood operate at full design airflows whenever full-load cooking activity occurs underneath an exhaust hood.

DCV has evolved from simple two-speed fan control systems to proportional control with variable frequency drives (VFDs) based on exhaust temperature. This improvement allowed for varying airflows throughout the day. Then, an optical sensor was added to the temperature-based control to detect cooking activity taking place under the exhaust hood to further enhance performance.

The latest system introduced to the market added measurement of exhaust airflow and automated balancing of multiple exhaust hoods connected to a single fan (or a dedicated fan) and modulation of replacement air for the space. Future systems need to be designed to consider the entire kitchen status to maximize energy savings.

Laboratory testing was conducted for common appliances in the commercial kitchen to evaluate system performance when equipped with various DCV algorithms: operating at a fixed exhaust

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setpoint temperature, operating on a temperature curve to increase exhaust airflow proportional to the temperature difference between exhaust and space temperature and operating on a temperature curve in combination with a cooking activity sensor (CAS) to drive the system to design when cooking is detected. Additionally, an evaluation was done to determine energy savings for a DCV system with balancing dampers installed on a four exhaust hood, island configuration.

Test Setup

The objective of the first round of tests was to compare performance of DCV systems that use temperature sensors only to those that incorporate cooking activity and temperature sensors. Currently, only two manufacturers offer the latter. One design uses optical opacity sensors to detect the presence of cooking effluent in a hood cavity. Another design uses infrared (IR) temperature sensors to monitor the surface temperature of cooking appliances. Data from these IR sensors along with space temperature and hood exhaust temperature sensors are analyzed to interpret the status of cooking appliances (idle, cooking or off) and adjust hood exhaust airflow accordingly.

A 72 in. (1.8 m) long wall canopy exhaust hood was configured to simulate various DCV control algorithms available on the market: exhaust temperature-based system that operates at a fixed setpoint, exhaust temperature-based system that operates on a curve and exhaust temperature coupled with a cooking activity sensor system (includes IR sensors).

Fixed setpoint exhaust temperatures of 90°F, 100°F and 130°F (32°C, 38°C and 54°C) were evaluated. For these configurations, the minimum exhaust airflow rate was 80% of design airflow rate (a common value for temperature only based systems due to the limited ability to detect when cooking starts and ramp-up of exhaust airflow). Exhaust airflow was varied by a VFD in an attempt to maintain the tested temperature setpoint.

For exhaust temperature systems that operated on a curve, the minimum exhaust airflow rate was again 80% of design. When using the curve, exhaust airflow was incrementally increased as the temperature difference between exhaust and kitchen space increased. This algorithm ensures C&C of convective heat from appliances installed under the hood.

Minimum exhaust airflow for the system with cooking activity sensors installed was limited to 40% of the design rate to ensure that the exhaust fans were operated in their recommended range. This system used the "curve" temperature control as described previously when appliances are in idle mode and transitioned to design exhaust airflow for an adjustable period (which was set to seven minutes for this test) upon detection of cooking activity. Following the timer expiration, if no new cooking activity is detected, the system returns to the "curve" control algorithm.

Appliance	Fuel Source	Loading	Design/Capture And Containment Airflow
600°F Charbroiler	Natural Gas	Frozen Hamburger Patties	1,800 cfm
400°F Griddle, Thermostatically Controlled	Natural Gas	Frozen Hamburger Patties	1,000 cfm
350°F Open-Vat Fryer, Single Vat	Natural Gas	Frozen French Fries	1,000 cfm

Table 1: Cooking appliance and associated food product.

The exhaust hood was installed at 80 in. (2 m) above finished floor with a temperature sensor mounted in the exhaust collar. The infrared sensors were positioned in the front, interior face of the canopy to sense the cooking surface. The temperature sensor was installed so that it was centered in the hood collar.

The test protocol included a range of appliances that all demonstrated similar trends, but due to space limitations only data for appliances most commonly seen in kitchens is presented: a charbroiler, griddle and open-vat fryer.

Airflows in *Table 1* represent hood C&C airflow, and whenever the hood operates below this value when cooking occurs, the hood is spilling. Details of appliance fuel source and product cooked are shown as well.

During testing, each combination was evaluated at the idle and cooking states. Exhaust airflow rate and temperature were plotted versus time. The onset of the cooking process was noted to determine system response time.

Results and Discussions

Charbroiler

Figure 1 summarizes testing conducted with the charbroiler, which exhibited the highest exhaust temperatures of all tested

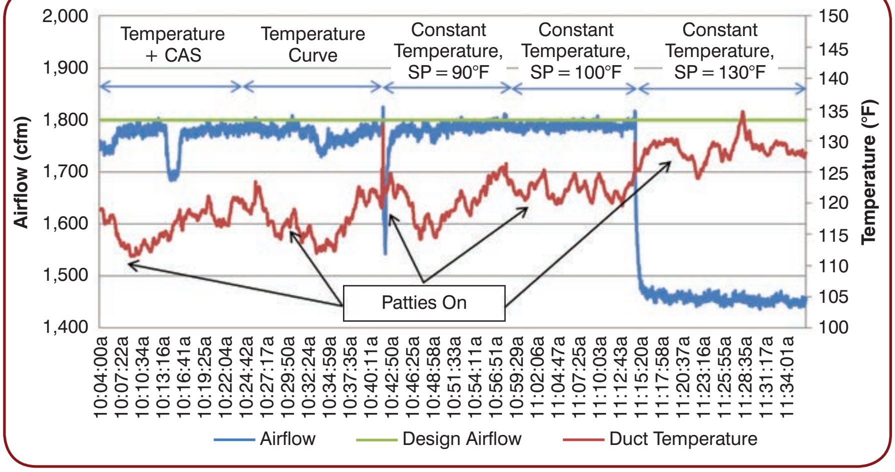

Figure 1: Charbroiler testing.

appliances. With the exhaust temperature and cooking activity sensor (CAS) algorithm, there was a small difference (approximately 5%) in idle and cooking exhaust airflow rates due to the elevated exhaust temperature. The cooking activity sensor was able to detect placement of patties on the cooking surface and force the system to design exhaust airflow, albeit a small change.

Following expiration of the cooking timer at approximately 10:13 a.m., the airflow rate dropped, but was forced back to design value as the exhaust temperature rose. With the tested algorithm, when the exhaust temperature exceeded 120°F (49°C), the system went to design exhaust airflow (regardless of the cooking activity sensor values signal) as this was the upper limit of the temperature curve.

Comparable results were seen with the temperature only system operating on a curve and constant temperature systems with a setpoint of 90°F and 100°F (32°C and 38°C). Due to an elevated exhaust temperature, the exhaust airflow remained at or near the design airflow level for the entirety of the test due to the temperature difference threshold of the operating curve being exceeded. When operated on the temperature curve, there was a small decrease in exhaust airflow at approximately 10:30 a.m. due to a decrease in exhaust temperature.

When the setpoint for the constant temperature system was changed to 130°F (54°C) the exhaust airflow dropped to 80% of design and remained there for the duration of the test as exhaust temperature did not exceed the setpoint. There was one exception where the exhaust temperature peaked at 134°F (57°C). Being 4°F (2°C) above the threshold, this value was within the deadband of the system. Had the temperature continued to rise, the exhaust airflow would have increased proportionally in an attempt to maintain a constant exhaust temperature.

It should be noted that with the charbroiler, the exhaust temperature rose steadily throughout the test as buildup on the cooking surface occurred. If the test had lasted longer, the exhaust airflow would have likely increased to design airflows for all tested systems.

Griddle

The results of the griddle testing are summarized in *Figure 2*. The exhaust temperature with the CAS algorithm operated at approximately 70% of design airflow at idle. The exhaust airflow was greater than the minimum setpoint of 40% to maintain C&C of heat generated by the appliance. When hamburger patties were placed on the surface, a decrease in surface temperature was noted as a cooking signal, and airflow was driven to design almost immediately, and fell back to idle after the cooking timer expired.

For an exhaust temperature-based system operating on a curve, exhaust airflow increased to the minimum idle rate of 80% of design. After patties were placed on the griddle, the airflow increased gradually with the exhaust temperature and then fell as the temperature decreased near the end of the cooking cycle. Note that airflow was not at design for the entirety of the cooking process.

When operating with a constant temperature setpoint of 100°F (38°C), the system was able to reach and maintain design airflow following placing patties on the cooking surface. However, the initial response was not as fast as obtained with the CAS.

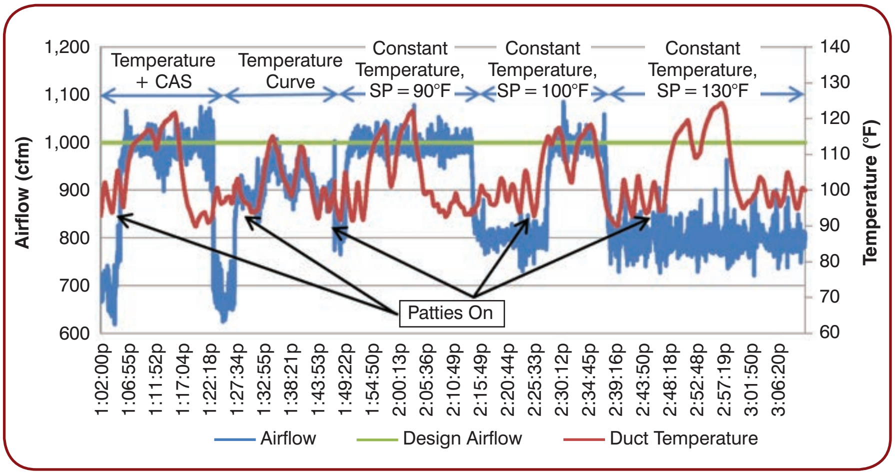

Figure 2: Griddle testing.

This test showed that the constant temperature setpoints of 90°F and 130°F (32°C and 54°C) were not suitable for the application. With a 90°F (32°C) setpoint the system remained at design airflow at all times due to the setpoint being lower than the exhaust temperature, even at idle conditions. A site configured to operate in this manner was no different than having a standard canopy hood without DCV. The opposite was true of the 130°F (54°C) setpoint. The system remained at idle airflow as the exhaust temperature never exceeded the setpoint, resulting in both heat and cooking effluent spilling to the space.

Open-Vat Fryer

Figure 3 shows data taken for the open-vat fryer. When testing with the CAS, the idle airflow rate fluctuated between

40% and 50% of design as the appliance fired to maintain oil temperature in the vat. Upon dropping the baskets of fries into the oil, the drop in temperature detected by the sensor indicated cooking was occurring and drove the exhaust fan to design airflow and then returned to idle after the cooking timer expired.

With the algorithm operating on a temperature curve, the system idled at the minimum prescribed 80% of design airflow and increased proportionally as the exhaust temperature rose. The temperature difference between exhaust and space did not exceed the upper limit to go to design airflow.

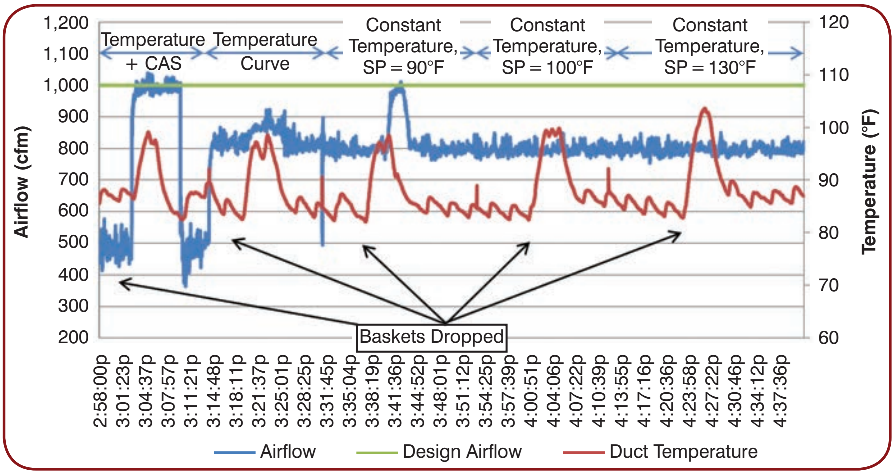

Figure 3: Open-vat fryer testing.

With the constant temperature setpoint configurations, all systems idle at 80% of design. When the setpoint was 90°F (32°C), the system did reach design airflow after the initiation of the cooking process, but a significant time lag between onset of cooking and meeting design airflow was noted. For 100°F and 130°F (38˚C and 54°C) configurations, the system remained idle at all times due to exhaust temperature not exceeding the setpoint. This was indicative of the requirement to be very familiar with the given cooking process when configuring temperature-based DCV systems. For example, the open-vat fryer potentially could perform better with a lower temperature setpoint value, but common practice dictates 90°F (32°C) and above setpoints to achieve any measurable airflow reductions.

Response Time

In addition to evaluating the exhaust airflow achieved with different types of DCV systems, the response times of the systems were compared as shown in *Table 2*. An entry of “N/A” indicates that the system either was not able to meet or remained at design airflow during the test. Note the response time of the systems with the CAS was substantially faster than the temperature-based systems. This is because the sensor actively monitors what is occurring at the appliance level, and can indicate when cooking occurs as soon as the product is placed in/on the appliance and drive the exhaust fan to design airflow for the entirety of the process; whereas, a temperature-based system can only react to a by-product of the cooking process: a change in temperature that takes longer to observe.

Appliance	Time From Start of Cooking (Seconds) When Design Airflow Reached				
	Temperature + Cooking Activity Sensor	Temperature Only Curve	Constant Temperature, SP=90°F	Constant Temperature, SP=100°F	Constant Temperature, SP=130°F
Charbroiler	23	N/A	N/A	N/A	N/A
Griddle	35	174	N/A	181	N/A
Open-Vat Fryer	23	N/A	297	N/A	N/A

Table 2: Response time comparison.

Discussion

The inclusion of the cooking activity sensor ensures the system goes to design airflow at the onset of the cooking process for tested appliances. When using only the temperature sensor, system response is more dependent on the correct selection setpoints and is always delayed. If improperly configured, temperature-based systems can operate at either idle or design airflow at all times, resulting in loss of C&C or no energy savings.

Each appliance shown has different exhaust temperatures that represent the transition from idle to cooking states. Rarely, appliances are configured so that each has a dedicated exhaust hood; the mixed lineup under a long hood is typical. Appliance lineups will vary from site to site, making a generic temperature curve or setpoint nearly impossible to obtain.

Some configurations can perform well without the CAS. For example, convection or conveyor ovens produce little to no smoke during the cooking process, which would be difficult for an optical opacity or infrared sensor to interpret. In some installations, a combination of temperature-based and temperature/CAS-based systems may be necessary for the system to perform at an optimal level.

Space temperature will vary during cooling and heating periods, affecting exhaust temperature as well. As a result the exhaust temperature setpoint must be adjusted from one season to another for DCV systems with exhaust temperature sensors only. A space temperature sensor installed in the area to constantly evaluate the difference between exhaust and room temperature maximizes energy savings potential of the DCV system.

Case Study: DCV With and Without Balancing Dampers

For installations where the exhaust hoods each have a dedicated exhaust fan, balancing dampers are not needed since the airflows can be modulated by changing the fan speed. However, when multiple exhaust hoods are connected to a single exhaust fan, balancing dampers listed in accordance with the UL 710 standard can be installed on each exhaust hood section to maximize the energy savings of a DCV system. This is because each hood needs to have the ability to independently regulate airflow based on its state (off, idle or cooking). To illustrate the energy savings that can be achieved with dampers installed, a site is evaluated with both configurations.

The examined site is in Seattle, and is a 24/7 operation. The only time the kitchen exhaust hoods are shut down is for a daily water-wash operation (approximately 15 minutes). The exhaust hoods are installed as back-to-back island style canopy hoods and are connected to a single exhaust fan (*Figure 4*). Each hood is fitted with a balancing damper at the exhaust collar. The DCV system operates with cooking activity sensors installed on all hoods. The design airflow for the site is 11,290 cfm (5328 L/s). *Figure 4* shows monitored data for exhaust fan speed. On average, the exhaust airflow rate was 73% of design. *Figure 5* shows the system rarely operated close to design airflows because the four hoods did not have cooking occurring at the same time.

Figure 6 shows the exhaust fan speed for the same DCV system and time period without the dampers installed. To model the system without dampers installed, hood status was also monitored with the fan speed and exhaust airflow data. These flags are generated by the control algorithm based on the inputs from the cooking activity, space and duct temperature sensor.

If one of the four hoods was in cooking state, that fan speed would increase to 100% to reach design airflow for the particular exhaust hood. If status was off or idle for all hoods, fan speed was assumed to be equal to that of the system with balancing dampers.

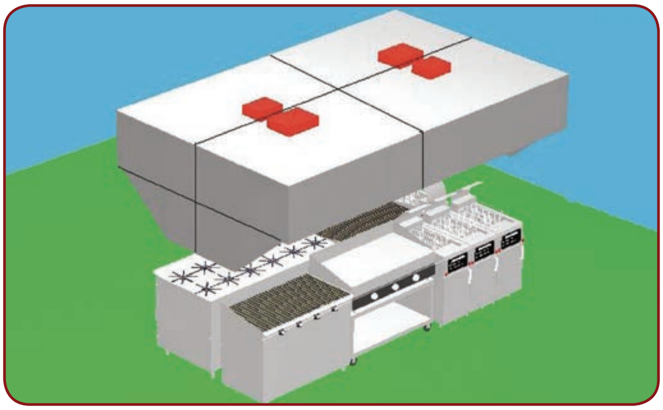

Figure 4: Examined site exhaust hood configuration.

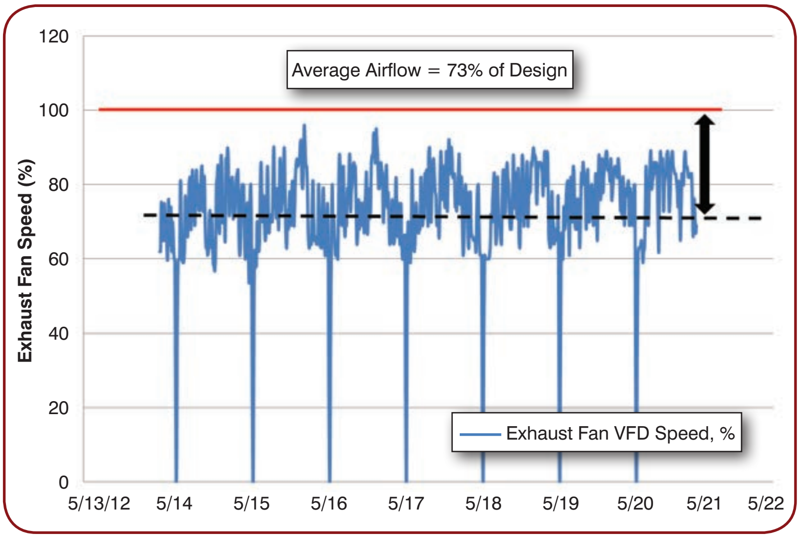

Figure 5: Case study with balancing dampers installed.

A fan speed profile for each configuration was generated to compare energy savings, rather than using average percent reduction alone. These profiles were used in conjunction with an outdoor air load calculator to determine savings associated with makeup air cooling and heating, as well as exhaust and supply fan energy. *Table 3* compares the annual energy savings associated with both configurations.

Although both configurations save energy, the installation of balancing dampers maximizes these savings by allowing the hoods to operate independently. Without dampers, when one hood is in the cooking state, all are forced to design airflow regardless of state. The value of the balancing damper lies in the ability to lower the airflows for hoods that are not cooking in single exhaust fan, multiple exhaust hood configurations.

In this particular case with four hoods connected to a single exhaust fan, the DCV system with balancing dampers saves nearly twice as much energy when compared to a similar system without balancing dampers. This is a conservative estimate because additional savings when all hoods are in idle mode are not accounted for. Indeed, when the DCV system is in idle mode (appliances are hot, but no cooking occurs), and the exhaust airflow is controlled based on a hood's exhaust temperature (more accurately the temperature difference between hood exhaust and space temperature) a dilemma is revealed: which exhaust temperature (or hood) should be used as a control signal for DCV without dampers?

The hood with the highest exhaust temperature would be the safest bet, but this would require a more sophisticated control algorithm (not the case for many DCV suppliers) and will still end up with a higher total exhaust airflow compared to DCV with dampers. In some cases, a fixed "leading" hood is assigned, and its exhaust temperature is used to control exhaust airflow for the whole system in DCV systems without dampers.

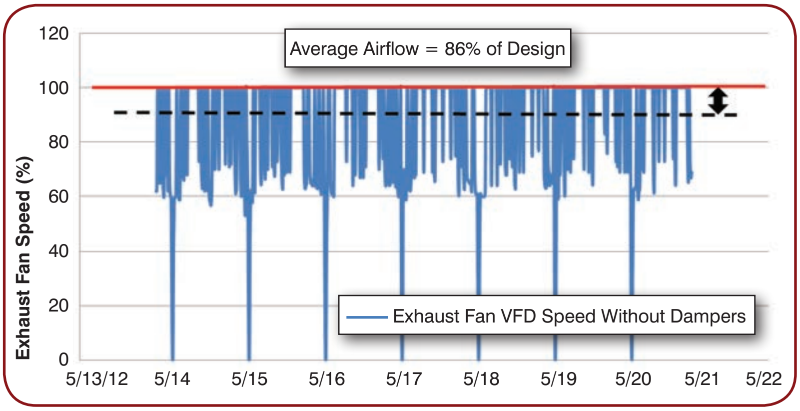

Figure 6: Case study without balancing dampers installed.

System	Estimated Savings			
	Heating (Therms)	Cooling (kWh)	Exhaust Fan (kWh)	Supply Fan (kWh)
DCV With Dampers	1,133	6,435	32,554	10,851
DCV Without Dampers	623	3,539	15,697	5,232
Difference	510	2,896	16,857	5,619

Table 3: Energy savings comparison with and without balancing dampers.

Future of DCV Systems

As evidence shows, the cooking activity sensor is an important component of an efficient DCV system. However, this is not the most effective way to identify appliance status. Taking a signal directly from the cooking appliance is a more effective way to detect appliance status (cooking, idle or off). Most modern cooking appliances are equipped with programmable logic controllers (PLCs) that already know appliance status. Establishing communication between the appliance and DCV controller is all that is needed.

As noted previously, cooking equipment and CKV are a kitchen's primary energy consumers. The term "demand control ventilation" implies that hood exhaust is modulated based on demand by cooking appliances under the hood. Cooking appliances define overall kitchen energy consumption because CKV energy consumption is, to a large extent, driven by appliances being used, and their status defining DCV exhaust airflow. However, DCV doesn't optimize the energy consumption of the source: the cooking equipment.

The next step in the development of an energy-efficient kitchen is implementing a demand-controlled kitchen (DCK) strategy, where appliances are controlled based on cooking demand and communicate their status to DCV to minimize CKV energy consumption. Indeed, how many times have you seen a range with all burners on and no pots on it or a triple-stack conveyer oven with all stacks on and just one conveyer being used? When we implement a DCK strategy with energy-efficient cooking appliances that are integrated with a DCV system (controlled based on cooking schedule and demand), we will have a truly energy-efficient kitchen.

Conclusions

Commercial kitchen DCV systems can offer great energy savings to the end user when properly implemented. Care should be taken to ensure the proper DCV system and sensor type are selected for a given appliance lineup.

Compared to DCV systems with cooking activity sensors, systems that use only temperature sensors can have significant lags in response time; more than two minutes in the evaluated cases of the open-vat fryer and griddle. Not detecting cooking in a timely manner results in loss of C&C, which allows heat and cooking effluent to spill to the kitchen space. Any savings associated with fan energy can quickly be offset by an increased load on cooling and heating equipment.

When temperature only systems are used, setpoints must be calibrated for a given application (appliance combination). This is key to ensuring the system operates as intended. Inappropriate setpoints can result in hoods that run at design airflow constantly (an expensive exhaust-only hood) or idle continuously (allowing spillage to occur). The setpoints also should be reset for winter and summer to account for variation in kitchen space temperature, unless a space temperature sensor is used for automatic reset.

Using automatic balancing dampers listed per UL Standard 710 for DCV systems with multiple hoods connected to a single exhaust fan significantly improves system energy efficiency. The energy savings for a four-hood system can be double when compared to an identical DCV system without balancing dampers.

References

1. NFPA. 2011. NFPA Standard 96-2011, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations.* National Fire Protection Association.

2. ICC. 2012. *2012 International Mechanical Code.* International Code Council. ■