Future of DCV
For Commercial Kitchens

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Conditioning the outdoor air to replace air exhausted from a commercial kitchen (along with the associated fan energy) imposes a significant energy burden—typically more than half of the total HVAC load in a commercial food-service facility. Although it is known that exhaust hoods do not need to operate at full-speed all day, adoption of demand-controlled ventilation (DCV) technology has been sluggish. However, changes to ASHRAE/IES Standard 90.1-2010 recognize DCV as a key attribute in the design of energy-efficient commercial kitchen ventilation systems, and the authors believe that DCV is poised to become standard practice within the design of commercial kitchens.

A primary component of all DCV systems is the variable frequency drives (VFD) on both the exhaust and makeup air fans. Integrated with a strategy to monitor appliance activity under the hood, the DCV system will modulate the exhaust and makeup air fans in concert with appliance use. While the concept of DCV for commercial kitchen ventilation (CKV) was pioneered by one manufacturer more than two decades ago, using a combined temperature and smoke detection system, other strategies of demand control have emerged, and the technology is now offered by at least eight manufacturers. The control strategies that are (or could be) used to "sense" appliance use and level of cooking activity include:*

• Time-of-day (using an energy management system with appropriate user override);

• Appliance energy use (requires metering and algorithms capable of distinguishing standby energy use from cooking energy use);

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• Sensing exhaust temperature (measured in the duct collar or in the hood reservoir) and/or temperature rise between kitchen and exhaust temperature;

• Sensing smoke or steam produced by cooking process using an infrared beam, combined with temperature sensing;

• Monitoring cooking surface temperature or activity using infrared beams, combined with temperature sensing; and

• Direct communication from cooking equipment controls to the DCV processor.

Types of DCV

Which one to choose: temperature-sensing-only DCV versus optics/cooking-activity-sensing combined with temperature-sensing DCV? This is an escalating debate within the industry as DCV systems gain traction in the design of CKV systems and as more systems are introduced. First, the authors believe that any type of DCV is better than no DCV (although there are projects where DCV is not going to be cost effective for either system).

Second, we believe that the potential turndown (average cfm reduction) for the more sophisticated DCV systems can be greater than the temperature-only systems. This is based on fan speed reduction during no-load (no cooking) periods and can be greater for optics-based DCV systems because of a quicker response time. However, if the cookline has high-heat producing, non-thermostatic appliances such as a charbroiler, conveyor oven or wok, the response time of the system may not be a significant factor and the performance of the temperature-only systems may more closely match the more complex optics-based systems.

The response time of a temperature-sensing system should be recognized as a factor in the design, particularly when thermostatic appliances such as fryers and griddles are specified. This is because the effluent produced during cooking may not be "seen" as quickly by the temperature probe in a duct collar that is providing a measure of the average exhaust temperature.

The economic return on a DCV package generally increases with the size of the project (i.e., larger exhaust systems in hospitals, hotels and casinos). It is also a fact the temperature-only DCV systems are less expensive than the more sophisticated optics/temperature based systems. However, the value proposition for investing in DCV is often based on rule-of-thumb estimates using a \$/cfm (\$/[L·s]) index (i.e., annual energy cost to operate the CKV system divided by the average exhaust ventilation rate), typically ranging between \$1 and \$3 per cfm (\$2 and \$6 per L/s) per year. If the \$/cfm (\$/(L·s) indicator has been derived from a computer simulation of a similar project in a similar location (e.g., from a LEED project), its application may be appropriate and relatively accurate. However, if the index has been casually selected, the resulting estimate of the system operating cost may under or overstate the savings.

The magnitude of the energy consumption and cost of a CKV system (or the DCV saving) is a function of the actual exhaust ventilation rate, geographic location, operating hours of the system, static pressure and fan efficiencies, makeup air heating setpoint, makeup air cooling setpoint and level of dehumidification, efficiency of heating and cooling systems, level of interaction with kitchen HVAC system, appliances under the hood and associated heat gain to space, and applied utility rates. While stating the obvious to the ASHRAE engineer, makeup air (MUA) heating and cooling loads vary dramatically across the continent. The MUA heating load in Minneapolis and Chicago can be a significant cost component, while in San Diego and Miami it may not exist at all. The reciprocal is true for cooling. And the latent energy component in Miami quickly differentiates itself from the desert climates.

Outdoor Air Load Calculator (OALC). The need for an easy-to-use tool that would accurately determine the heating and cooling load for a given amount of outdoor (makeup) air led to the development of a no-cost, publicly available software tool, the Outdoor Air Load Calculator (OALC).[1] Since this tool does not model a complete building in detail, the minimal required input parameters are geographic location, outdoor airflow, operating hours, and the heating and cooling setpoints. With these basic inputs, the OALC is able to calculate monthly and annual heating and cooling loads, as well as design loads (the maximum heating and cooling load that occurred during the year). Through a "Details" menu it is possible to further customize the calculation setup for dehumidification, equipment lockout during parts of the year, and fan characteristics for estimating exhaust and makeup air fan energy consumption. The versatility of the OALC allows simulation of a variety of scenarios, but it also places responsibility on the user to carefully choose the parameters. Casual selection of user inputs may result in unrealistic results. This tool was used as the foundation for an ASHRAE Journal article.[2]

DCV and Codes

A significant obstacle to the adoption of DCV in commercial kitchens in the past was the minimum 1,500 fpm (8 m/s) duct velocity requirement dictated by National Fire Protection Association Standard 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*. Since 1,500 fpm (8 m/s) was a reasonable velocity for sizing ductwork, CKV systems typically were designed within the range of 1,500 to 1,800 fpm (8 m/s to 9 m/s). Therefore, if a DCV control strategy was selected that could potentially reduce the exhaust airflow below 1,500 fpm (8 m/s) during periods of light cooking, this fire-safety code was at risk of being violated.

In response to this issue, a 2000 ASHRAE research project, RP-1033, *Effects of Air Velocity on Grease Deposition in Exhaust Ductwork*, concluded that duct velocity was not a significant driver of grease deposition in Type I ductwork. As a result, NFPA

*This article reports only performance data for the strategy that comprises both sensing temperature and sensing smoke/steam using an infrared beam. With the recent availability of various temperature-based-only systems and ongoing field monitoring, the authors anticipate a future Journal article presenting data for such DCV systems.

relaxed the minimum duct velocity from 1,500 to 500 fpm (8 m/s to 3 m/s) in 2001, opening the door to proportional control of the exhaust ventilation rate during periods with lighter levels of cooking. A 2003 ASHRAE Journal article stated that such code changes should "open the floodgates" for DCV in commercial kitchens.[3] But the floodgates did not open very wide!

Recognition of DCV as a best practice for an energy-saving design had its genesis in the kitchen ventilation chapter of the *2011ASHRAE Handbook—HVAC Applications* and in the standing standards project committee that wrote the 2003 edition of ASHRAE Standard 154, *Ventilation for Commercial Cooking Operations*. The Standard 154 committee recognized the value of multispeed and variable speed ventilation systems as an energy-saving strategy. Standard 154 committee members worked with the International Code Council to allow multispeed kitchen exhaust systems in the 2003 edition of the International Mechanical Code.

Since that time, ASHRAE/IES Standard 90.1 adopted a more aggressive approach that included requirements for transfer air, demand-controlled ventilation, energy recovery devices and high performance hoods. The revisions to Standard 90.1 were adopted as an addendum and were incorporated into the 2010 edition. Other code writing bodies began seeing the importance of encouraging DCV. The Standard 90.1-2010 version exists in whole or in part in many other codes and standards such as ASHRAE/USGBC/IES Standard 189.1-2011 and International Association of Plumbing and Mechanical Officials' Green Plumbing and Mechanical Code Supplement.

In January 2014, California's Building Energy Efficiency Standard (Title 24) will be adopting similar language. The 2012 edition of the International Green Construction Code (IgCC) refers to the DCV language in Standards 90.1-2010 and 189.1-2011. The Uniform Mechanical Code has had provisions for multispeed systems since its 2004 edition.

DCV and the Designer

The cornerstone of a DCV system is the complement of VFDs that allow the DCV microprocessor to modulate the exhaust and makeup air fan speed in response to cooking appliance activity. It also provides speed adjustment necessary if a direct-drive fan is to be used. Without a VFD, usually the speed of a direct-drive fan cannot be field adjusted, and the ability to balance airflow on a CKV system is virtually impossible. It has been the authors' position for many years that restaurant HVAC designers consider using direct-drive fans with VFDs regardless of whether they plan to pursue DCV technology. The benefits of eliminating broken belts and gaining an increase in fan efficiency are obvious, but again, the food-service design community has been reluctant to adopt this technology on a wide-scale basis. That said, a VFD could be successfully applied to an existing belt-driven fan as the foundation for a DCV system.

The designer needs quick and easy access to the DCV components to design and specify a DCV system that performs well for the cooking application. The hood and fan sizes can be easily designed and laid-out with online software. The exhaust airflow design rates can be determined by the appliance line and guidance in the Handbook, Standard 154-2011 or similar standards. The hood static pressure can be found from hood filter and collar design calculations.

However, integrating hoods, fans, and speed controllers can be difficult. It is not always easy to determine which components are necessary to build the variable speed package. Are the fans supplied with a direct drive speed controller, or does a separate VFD need to be specified? How will the fans, hoods and appliances communicate? What are the lower speeds and airflow rates of the variable speed system during off-peak conditions? How will the system be interlocked and maintain the air balance and pressurization? How will hood performance be verified at the various speeds? When the replacement air is not supplied through a dedicated makeup air unit, some method of reducing the outdoor air being supplied through the HVAC system must be incorporated. A DCV system should be able to effectively communicate/integrate with an EMS system if it is specified within the facility design. An auto-shutdown feature is another important attribute of an integrated DCV system.

Some manufacturers with online software are able to assemble a variable speed motor package that integrates with the hoods without too much difficulty; some are more detailed than others (including wiring diagrams, etc.). However, many manufacturers leave too many questions to be answered with too little information available. The result could be a poorly designed and improperly installed DCV system that lacks performance and proves disastrous for the chef and owner and, as a result, gives a bad name to a system that could revolutionize the industry.

It is critical to recognize that an exhaust hood needs to effectively capture and contain the heat and smoke generated by the cooking equipment when the hood is at its full speed—before installing or engaging the DCV system. Although energy-conscious system design dictates an exhaust ventilation rate that is not excessively high, sometimes this leads to inadequate performance if erred on the low side. Fortunately, with the specification of a DCV system and ability to "commission out" a safety factor, there is no need to take chances with a design exhaust ventilation rate that might not be adequate.

DCV System Field Monitoring Data

DCV system data was collected from field-monitoring case studies (conducted in collaboration with the California Investor Owned Utilities) at a total of 11 sites that reflect the range in commercial food-service operations and exhaust ventilation system design. The data compiled in *Table 1* was used to determine the fundamental parameters upon which the saving model was based and to assign statewide utility rebates. All DCV systems included in this field study comprised a combination of temperature- and optics-based sensors. Field monitoring protocol was generally in accordance with a consensus-based guideline developed by a consortium, whose members are efficiency program administrators and energy efficiency non-profits from the U.S. and Canada.[4]

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	Institutional Cafeteria (San Ramon)	Casual Dining Restaurant (Rancho Cucamonga)	Hotel Main Kitchen (a) (San Francisco)	Supermarket (Brentwood)	University Campus Dining Facility (a) (Berkeley)	University Campus Dining Facility (b) (Santa Barbara)	Hotel Main Kitchen (b) (Palm Desert)	Hotel Main Kitchen (c) (Rancho Mirage)	Quick Service Restaurant (a) (El Monte)	Quick Service Restaurant (b) (Quartz Hill)	Quick Service Restaurant (c) (Irwindale)	Average of All Projects
Rated Exhaust Fan Power (HP)	6.0	3.0	15.0	n/a	8.0	20.0	21.0	14.0	3.0	4.0	2.5	9.7
Baseline Exhaust Fan Power (kW)	4.2	2.3	7.6	6.3	6.20	6.5	19.0	9.3	2.8	4.1	2.9	6.5
Baseline Makeup Air Fan Power (kW)	3.1	1.5	6.4	n/a	6.50	5.5	9.0	3.7	1.9	1.3	n/a	4.3
Baseline Total Fan Power (kW)	7.3	3.9	14.0	6.30	12.70	12.0	27.9	12.1	4.7	5.2	2.9	9.9
Total Fan Power w/DCV (kW)	1.9	2.1	5.3	1.20	5.8	6.6	10.7	5.2	2.9	2.0	1.4	4.1
Operating Time Per Day (h)	19.0	17.0	24.0	12.0	17.0	17.0	24.0	24.0	15.0	13.0	16.0	18.0
Operating Days Per Year (d)	260	363	365	360	300	350	365	365	365	365	365	348
Total Fan Power Reduction (kW)	5.4	1.8	8.7	5.1	7.0	5.4	17.2	6.90	1.8	3.20	1.50	5.8
Total Fan Power Reduction (%)	74.0	46.0	62.0	80.0	55.0	45.0	62.0	57.0	38.0	62.0	52.0	57.0
Exhaust Fan Speed Reduction (%)	36.0	18.0	28.0	42.0	23.0	18.0	27.0	25.0	15.0	27.0	22.0	26.0
Annual Baseline Fan Energy (kWh/yr)	35,900	21,400	122,600	27,400	65,100	71,400	244,600	106,200	26,300	24,500	16,100	69,200
Annual Fan Energy w/DCV (kWh/yr)	9,100	11,600	46,400	6,500	29,400	39,300	93,800	45,600	16,400	9,500	8,400	28,700
Annual Fan Energy Savings (kWh/yr)	26,800	9,800	76,300	20,900	35,700	32,100	150,800	60,400	9,900	15,100	7,900	40,500

Table 1: Field data for DCV systems in a variety of food-service operations.

The data in *Table 1* and *Figure 1* presents the total fan power and fan speed reduction as measured for the 11 sites. All the sites are within the climate zones of California. However, the data was independent of the outside air conditions. The data represent the average total fan energy savings of 57% and an average reduction in exhaust airflow rates of 26%. The total fan power and exhaust fan speed reductions are time-weighted averages for the individual sites. The actual instantaneous reductions vary between the 100% maximum speed required at full-load cooking conditions and typically 50% of maximum speed during idle (ready-to-cook) conditions. This modulation is illustrated in *Photo 1* (Page 48) and *Figure 2,* which shows the exhaust fan power levels for a wall-mounted canopy hood being operated in a university campus dining facility.[5]

While the heating and cooling load reductions were not calculated and reported, these loads can be predicted for any climate zone using the OALC applying the average speed reduction (i.e., reduction in cfm). A guide to these calculations was reported in a previous ASHRAE Journal article.[2]

Conclusions

Comprehensive field monitoring of DCV systems within different types of commercial food-service facilities has documented the energy-saving potential of this variable speed tech-

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nology while providing justification for the financial incentives being offered within utility energy efficiency programs. The data also supports the adoption of DCV technology within energy codes and standards. However, at this time, the authors do not have published field monitoring data for the temperature-sensing-only DCV systems to be able to report on the energy performance for this subset of DCV technologies. It is anticipated that DCV system monitoring will be ongoing and that data will evolve that will characterize the performance of the other DCV options on the market.[8]

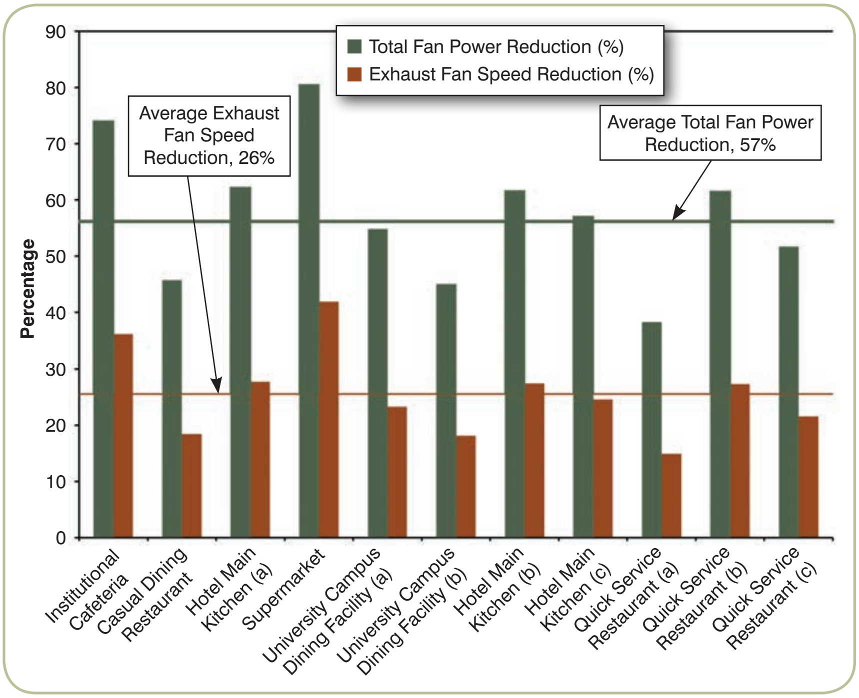

Figure 1: Average fan speed & fan power reduction for field monitored DCV sites.

As appliance-use sensing strategies and DCV control algorithms evolve, along with commissioning protocols, the authors believe that the energy-saving potential of DCV systems will increase and continue to improve the return on investment for the building owner. Just as appliances' communication platforms advance to monitor temperatures, maintenance issues, on time and product mix, the same information can be used to establish exhaust rates based on which appliances are cooking what product and for how long. A plug-and-play type sophistication would streamline the process to maximize hood performance for a type of appliance/hood configuration, while minimizing the fan and makeup air, tempering energy use.

Beyond the DCV system design and installation, the facility management side must "take ownership" if DCV technology is to be successfully deployed. Education of staff is a key ingredient for a successful installation. If they don't understand the value, and existing hood problems are not fixed, they will quickly learn how to override the system. The authors find in their food-service fieldtrips that many DCV systems are working just fine, while others have been overridden by one means or another. And we have also learned that effective fine-tuning during commissioning of a DCV system can maximize its performance (which is often a neglected piece of the commissioning specification).

While DCV has been a key measure incorporated within LEED projects, the authors believe that demand-controlled ventilation is positioned to move from *best practice* to *standard practice*. But the journey is not over. Until the industry adopts VFDs as an independent value proposition and the cooking equipment develops the "intelligence" to communicate with the DCV processor, the cost and performance limitations of DCV will continue to challenge the industrywide adoption of the technology. We look forward to a future where single-speed kitchen exhaust ventilation systems are history!

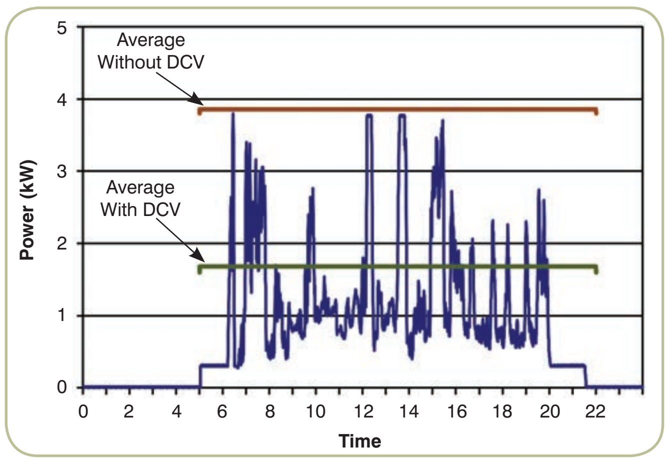

Figure 2: Typical rear exhaust fan power profile for a campus dining facility.

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