ENERGY EFFICIENT SOLUTIONS
FOR COMMERCIAL KITCHEN VENTILATION

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Introduction

Restaurants are among commercial buildings with the highest energy consumption per building area. Cooking equipment and restaurant HVAC system are the primary energy consumers, both of these systems contribute up to 80 % of the total restaurant energy consumption. Path to an energy efficient restaurant design always starts from the heat source – cooking process and equipment. Low efficiency appliances with high energy output add more heat to the kitchen space; require higher ventilation rates resulting in a higher HVAC energy consumption. More efficient cooking equipment, such as induction cookers and combi-ovens for example, consume less energy to prepare food and release less heat to kitchen space hence requiring

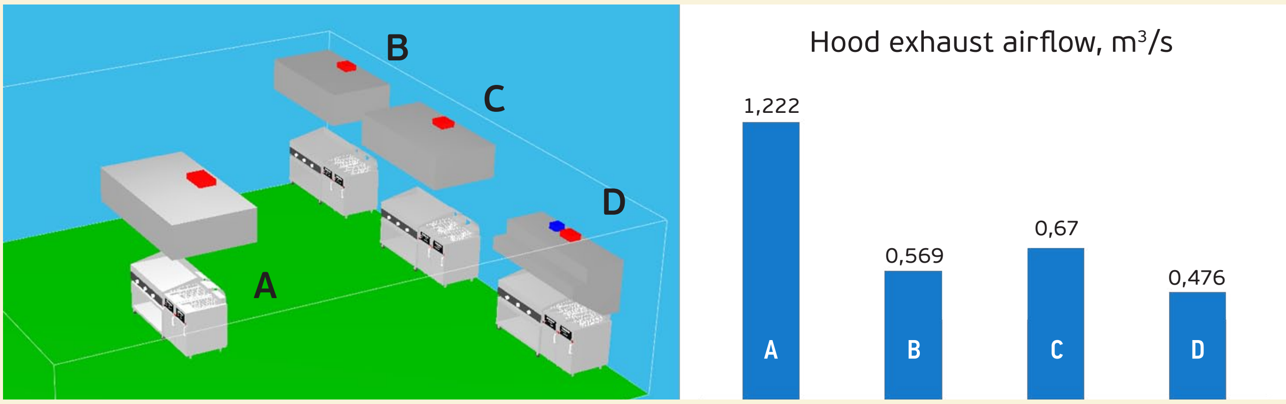
less energy to ventilate and cool the kitchen.

Next step in the energy efficient design is optimization of HVAC system – subject of this paper. Exhaust hood airflow is its most important component of HVAC design because it drives HVAC energy consumption for CKV. Indeed, the higher hoods exhaust airflow, the higher the electricity consumption by exhaust and supply fan motors as well as the energy required to cool or heat replacement air supplied into kitchen space to compensate for hoods' exhaust.

How to minimize hood exhaust airflow

1. Position cooking appliances close to the walls, avoid island installations when possible. Use side skirts on the hood to enclose cooking appliances and contain their thermal plumes. Figure below demonstrates how appliance position and hood selection affects hood exhaust airflow. Same appliances (gas griddle and two-vat open fryers) were used in four cases compared. In case A appliances are positioned in the middle of the kitchen and canopy island style hood is used. Convective plume, rising from appliances, is not restricted by walls and is subject to cross-drafts in the kitchen. Canopy island hood would need to operate at 1,222 m^3/s exhaust airflow to capture convective heat and effluents from appliances. If we were to move cooking appliances in the corner (case B) and also use canopy-style hood, its airflow will drop to 0,569 m^3/s. This is explained by the fact that convective plume rising from hot cooking surfaces attaches to walls; it carries less air at the hood level thus requiring less exhaust airflow to capture it and contain. If we were to move appliances from the corner, but still position them near the wall (case C), exhaust airflow will slightly increase to 0,67 m^3/s compared to case B. This is explained by the fact that convective plume rising from hot griddle surface, attaches only to one wall and carries slightly more air compared to the case when griddle is in the corner, surrounded by two walls. Finally, in case D we bring hood closer to cooking appliances and use high efficiency, close proximity back-shelf hood with side skirts. This allows further to drop exhaust airflow to 0,476 m^3/s.

FIGURE 1. EFFECT OF APPLIANCE POSITION AND HOOD SELECTION ON EXHAUST AIRFLOW



A – appliances in the middle of the space with canopy island hood;
B – appliances in the corner with canopy wall hood;
C – appliances at the wall with canopy wall hood;
D – appliances at the wall with close proximity back-shelf hood.

As you can see from this example, moving cooking appliances from the middle of the kitchen to a wall and using back-shelf hood allowed reducing hood exhaust airflow from 1,222 to 0,476 m^3/s, this is 61 % airflow reduction. For a typical restaurant in Sao Paulo operating 14 hours per day it will result in 7 000 kWh annual electricity saving.

2. Use high efficiency hoods. It is a common misconception that hood is just a metal box, no matter which hood design is being used they all operate at the same capture and containment (C&C) airflow. This is not true. As with the high efficiency cars, where designers use CFD (Computational Fluid Dynamics) modelling to reduce car drag coefficient, best hood designs also use similar tools to optimize aerodynamic shape of the hood and introduce activated air curtains to reduce hood C&C airflow. Figure below shows CFD simulation of two hoods operating at the same exhaust airflow. Picture on the left shows hood spilling convective plume and effluent from hot appliance into the kitchen space. Hood on the right operates at C&C airflow capturing convective plume and effluent from cooking appliance, it utilizes row of nozzles supplying ambient air and forming air curtain around lower edge of the hood.

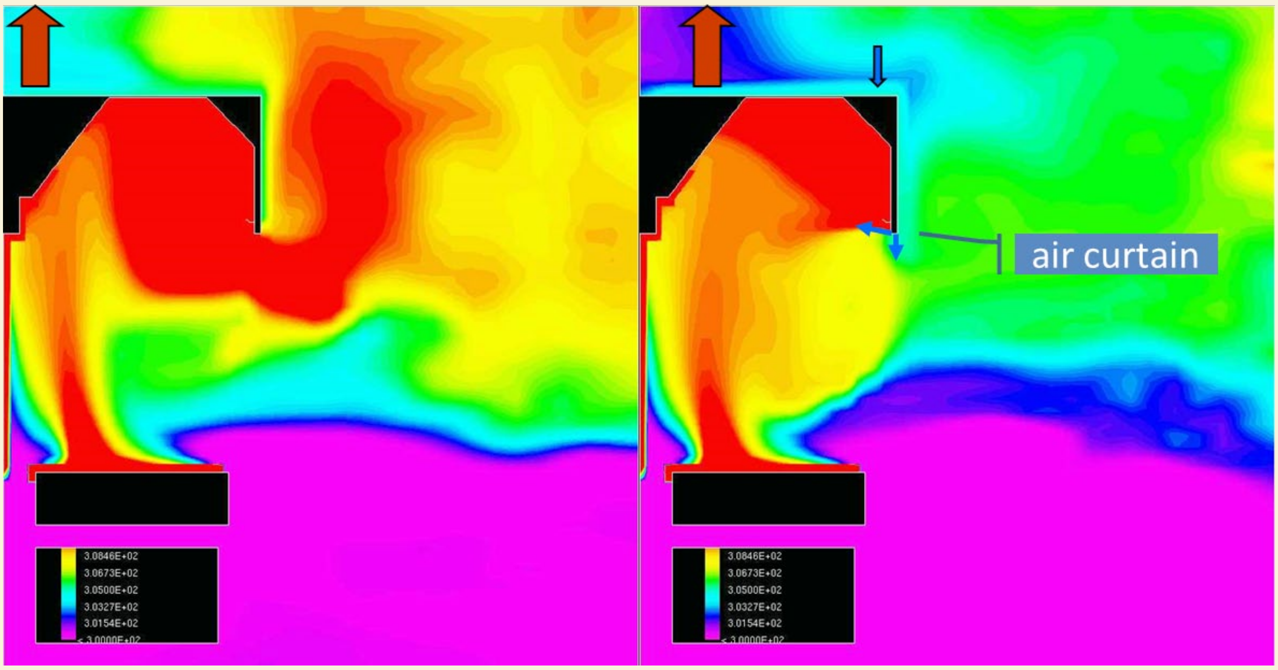
Figure 3 illustrates similar to Figure 2 conditions, but in this case using Schlieren photography of two hoods tested in laboratory conditions over gas charbroiler with 316 °C cooking surface temperature. Experiments demonstrated that in order for the hood on the left (without activated air curtain) to achieve C&C exhaust airflow, its exhaust airflow would need to be increased by 30 % compared to the hood on the left with the air curtain.

3. Use Demand Control Kitchen Ventilation (DCKV). Studies show that even busiest restaurants utilize their cooking equipment only 20 %. That means that any given cooking appliance is used to prepare food only 20 % of time and 80 % of time is in stand-by mode ready to cook. This creates an opportunity to further reduce hood exhaust airflow when appliances under this hood are off or in idle condition and not cooking.

Figure 4 Demonstrates performance of DCKV for a typical quick-service restaurant. On average it allowed to reduce exhaust airflow by 43 % from 8 469 to 4 783 m3/s.

DCKV is relatively new system, but already there are quite a few variations of it are being offered on the market. DCKV systems can be divided into two categories: «temperature – only» and systems where temperature sensors are complimented by additional sensors detecting cooking activity of appliances underneath the hood.

FIGURE 2. CFD SIMULATION OF TWO HOODS OPERATING AT THE SAME EXHAUST AIRFLOW



On the left – hood without air curtain spilling convective plume from hot appliance into the kitchen.
On the right – hood with activated air curtain operating at C&C airflow.

FIGURE 3. SCHLIEREN PHOTOGRAPHY OF TWO HOODS OPERATING AT THE SAME EXHAUST AIRFLOW AND TESTED IN THE LABORATORY

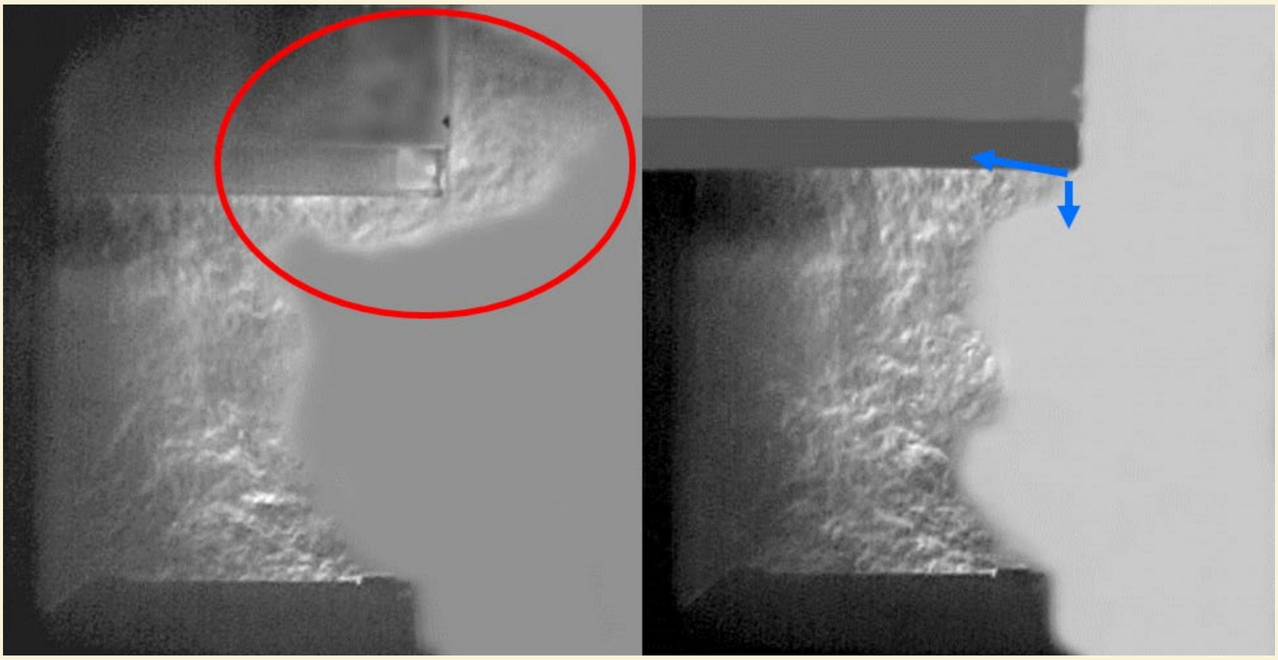
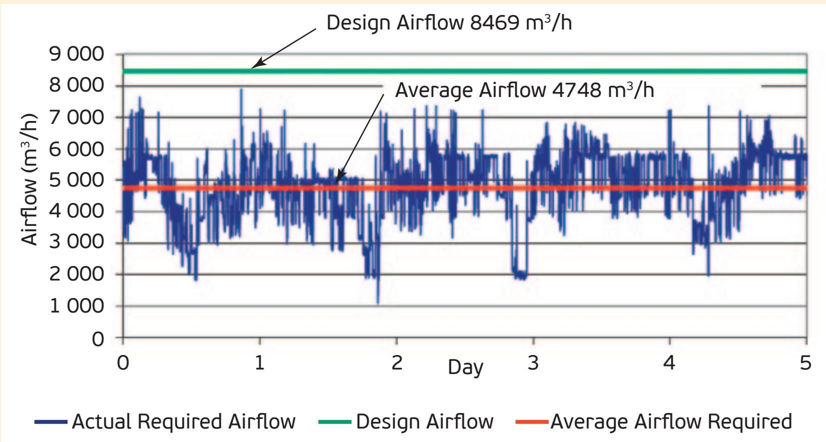


Photo on the left shows hood without air curtain and spilling. Photo on the right shows hood with activated air curtain and operating at C&C airflow.

First DCKV category, typically called «temperature-only» system, utilizes air temperature sensors installed in a hood's exhaust collar or within a hood canopy. Control logic for such systems is fairly simple; it attempts to maintain pre-set temperature by regulating hood exhaust airflow. As hood exhaust temperature exceeds setpoint, exhaust airflow is increased; when exhaust temperature drops below setpoint, hood airflow is reduced. Some more sophisticated «temperature-only» systems utilize temperature difference between ambient air temperature in the kitchen and hood exhaust temperature in their algorithm. This eliminates the need to change setpoints for hood exhaust temperature when transitioning from heating to cooling season and back. Kitchen air temperature may vary as much as 10 °C or more between summer and winter. Similar variation is true for the hood exhaust air temperature and if a DCKV system is commissioned for example in summer and exhaust temperature setpoint is determined to be 38 °C for a given cooking line, it would need to be reset when winter comes and exhaust temperature drops as result of a lower kitchen space temperature.

Second, more sophisticated DCKV category relies on exhaust and kitchen space temperature sensors only when appliances are in idle mode and utilizes additional cooking activity sensors to detect when cooking started

FIGURE 4. PERFORMANCE OF DCKV FOR A TYPICAL QUICK-SERVICE RESTAURANT



and increase hood exhaust airflow to design level as soon as possible. There are two designs of DCKV system with cooking activity sensors currently on the market. One uses light emitter and receptacle installed at the ends of the hood canopy. Whenever beam of light shooting across hood canopy is obscured by smoke or steam, cooking status is detected and hood exhaust airflow is increased to design level. Another DCKV design, shown on Figure 5, utilizes infrared (IR) temperature sensors spaced evenly within hood canopy. These IR sensors continuously monitor surface temperature of cooking appliances underneath the hood. Whenever sudden change up (flare-up) or down (cold product on a hot surface) of cooking surface temperature is detected, this event is identified as cooking and the hood exhaust airflow is increased to design level for a pre-set cooking time period or until next cooking event is detected.

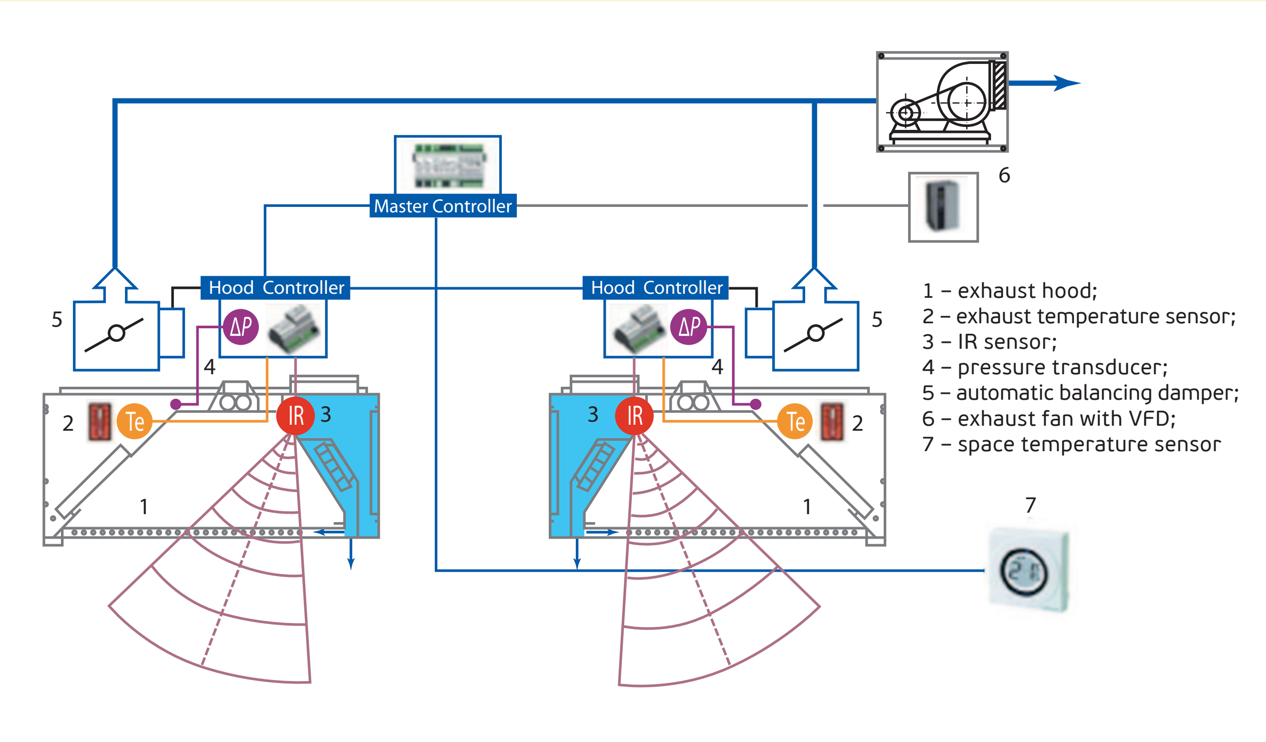
Airflow reduction is not the sole objective of a DCKV system; it also needs to make sure exhaust airflow and the corresponding supply airflows are increased to C&C levels as soon as cooking starts to avoid spillage of convective heat and cooking effluent into the kitchen space. The current NFPA-96 Standard (NFPA, 2011) [1] and International Mechanical Code (BOCA, 2012) [2] require that the hood operate at full design airflows whenever full load cooking activity occurs underneath a hood. Comprehensive study published in ASHRAE Journal in 2012 [3] compared performance of «temperature-only» and DCKV system with cooking activity sensor and came to conclusion that «temperature – only» systems fail to detect beginning of cooking process. This results in spillage of cooking effluent and limited energy saving potential of these systems. The inclusion of the cooking activity sensor helps to ensure that the system goes to design airflow at the onset of the cooking process.

It should also be noted that each appliance has different exhaust temperatures that represent idle and 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 set-point nearly impossible to obtain for temperature-only DCKV systems.

DCKV and balancing dampers

For installations where each exhaust hood has 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

FIGURE 5. DCKV SYSTEM WITH COOKING ACTIVITY SENSOR



to a single exhaust fan, balancing dampers can be installed on each exhaust hood section to optimize the energy savings of a DCV system. This is because each hood needs to have the ability to independently regulate the airflow. If no balancing dampers installed, whole DCKV system operates as a single hood; whenever cooking occurs under one hood, whole system operates at design airflow.

To illustrate the energy savings that can be achieved with dampers installed, a site is evaluated with both configurations.

The examined site is located in Seattle, Washington and is a 24/7 operation. The only time the kitchen exhaust hoods are shut down is for a daily water-wash operation (approximately fifteen minutes). The exhaust hoods are installed as back-to-back island style canopy hoods and are connected to a single exhaust fan. 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 (5,328 L/sec). Figure 6 shows monitored data for exhaust fan speed. On average the exhaust airflow rate was 73 % of design. It can be observed in that the system rarely operated close to design airflows because the four hoods did not have cooking occurring at the same time.

Figure 7 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, fan speed would increase to 100 % to reach design airflow for the particular exhaust hood. Table 2 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 to idle levels 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

FIGURE 6. CASE STUDY WITH BALANCING DAMPERS INSTALLED

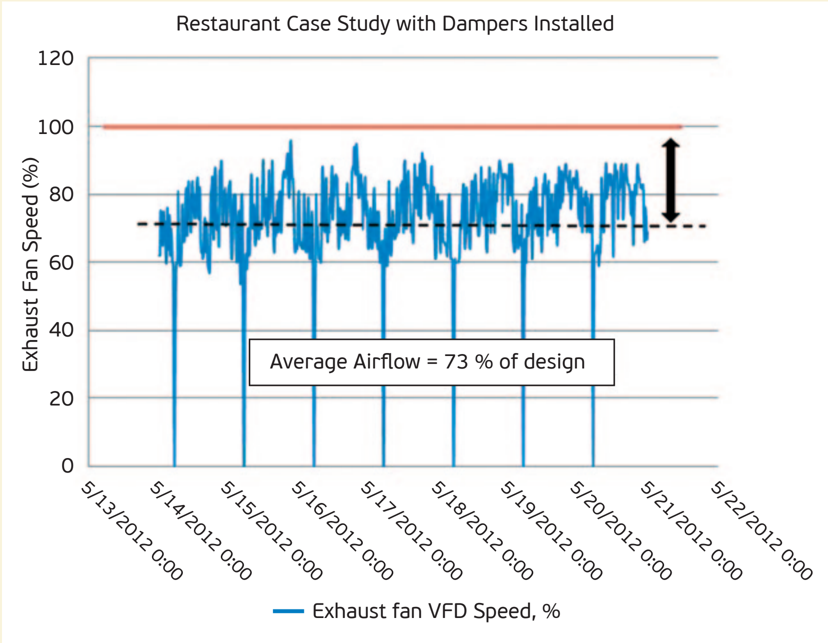


FIGURE 7. CASE STUDY WITHOUT BALANCING DAMPERS INSTALLED

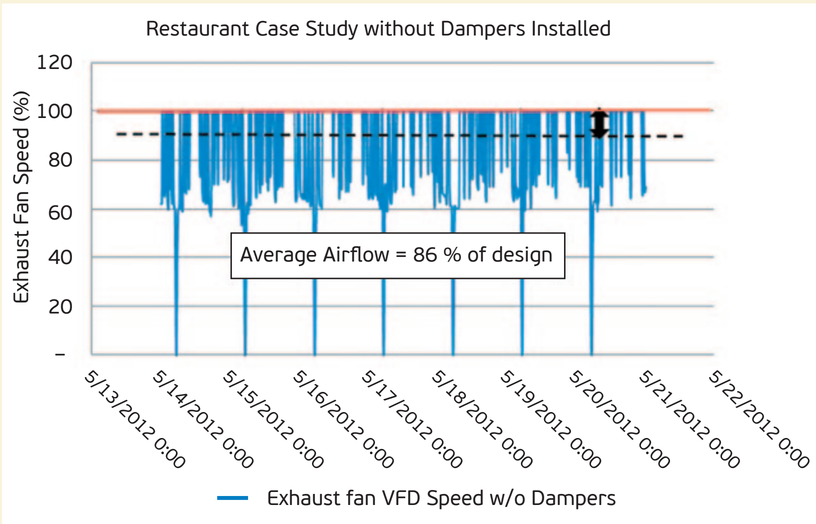


TABLE 2. ENERGY SAVINGS COMPARISON WITH AND WITHOUT BALANCING DAMPERS

System	Estimated Savings			
	Heating, Therms	Cooling, kWh	Exhaust Fan, kWh	Supply Fan, kWh
DCV w/ Dampers	1133	6435	32554	10851
DCV w/o Dampers	623	539	15697	5232
Difference	510	2896	16857	5619

fan, the DCV system with balancing dampers saves much more energy when compared to a similar system without balancing dampers. Additionally, when the DCV system is in idle mode (appliances are hot, but no cooking occurs), and the exhaust airflow is controlled based on a hoods exhaust temperature (more accurately 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.

Future of DCV systems

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 PLC controllers that already know appliance status and all that is needed is to establish communication between appliance and DCV controller.

As noted above, cooking equipment and CKV are kitchens 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 to a large extent is driven by appliances being used and their status defining DCV exhaust airflow. DCV, however, doesn't optimize the energy consumption of the source – cooking equipment itself. The next step in the development of an energy efficient kitchen is implementing 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? Only when we implement DCK with energy efficient cooking appliances integrated with DCV system controlled based on cooking schedule and demand will we have a truly energy efficient kitchen.

4. Pay Attention to Air Distribution Design. Air distribution system has important effect on hoods performance capture and containment (C&C) exhaust airflow. Convective plume rising above hot cooking surface is a slow moving flow and even slight cross-draft of 0,3 m/s or higher can cause this plume bend and spill out of a hood. Design air distribution system to provide sufficient air around hood perimeter to compensate for each hood in kitchen space. Use low velocity perforated diffusers to avoid high velocity in kitchen spaces.

Conclusions

Menu for energy efficient design:

- Start optimization from cooking process and equipment.
- Design ventilation system that is tailored for this particular cooking process, minimize hood exhaust airflow.
- Use Demand Controlled Kitchen Ventilation to further reduce hoods exhaust airflow.
- Design air distribution system to avoid cross-drafts in the space and provide sufficient replacement air for each hood in the kitchen.

References

1. National Fire Protection Association. 2011. NFPA Standard 96–2011, Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations.
2. International Code Council. 2012. 2012 International Mechanical Code.
3. D. Schrock, J. Sandusky, A. Livchak «Demand-Controlled Ventilation for Commercial Kitchens», ASHRAE Journal, Nov. 201. ●

НОВЫЙ АНГЛО-РУССКИЙ, РУССКО-АНГЛИЙСКИЙ СЛОВАРЬ

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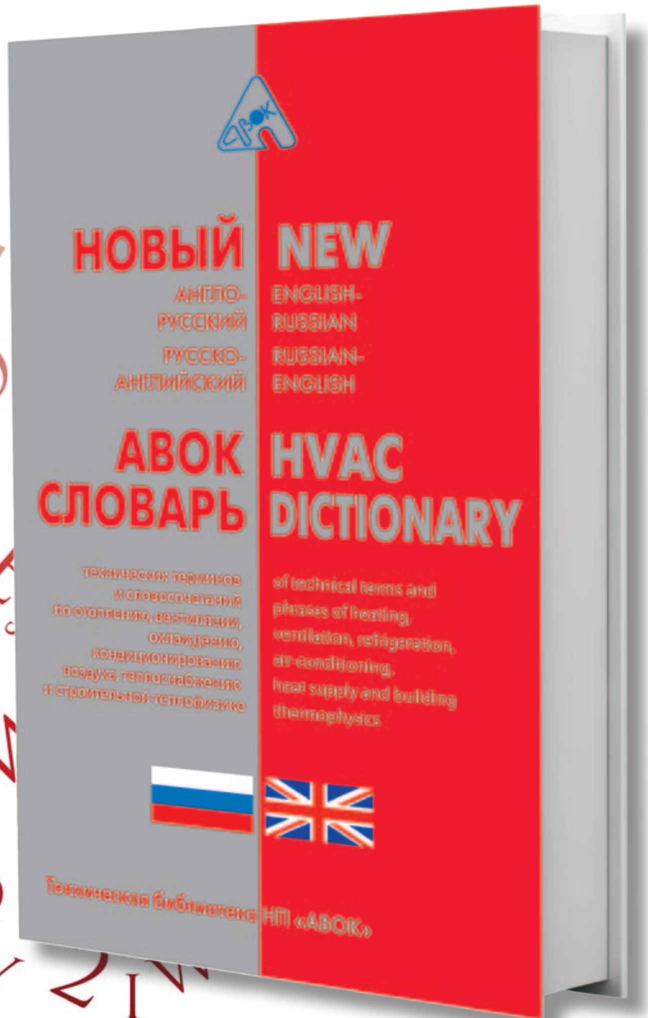

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