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Controlling Ventilation and Space Depressurization in Restaurants in Hot and Humid Climates

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Synopsis

Testing was performed in 9 restaurants to identify uncontrolled air flows and pressure imbalances, building and duct system airtightness, building air barrier location, pressure differentials, building air flow balance, and ventilation rates. All restaurants are depressurized under normal operating conditions, ranging from -1.0 to -43 pascals. Space depressurization is a function of exhaust fan flow rates, missing or undersized make-up air, intermittent outdoor air caused by the cycling of air handlers, dirty outdoor air and make-up air filters, and building airtightness. Ventilation rates were found to be high, generally exceeding ASHRAE 62-1989 minimum recommended levels. Pressure imbalances and excessive ventilation rates impact energy use, heating/cooling system sizing, indoor comfort and humidity, building moisture damage, mold growth, combustion equipment problems, and indoor air quality.

The objectives of good restaurant air flow management (in hot and humid climates) are to: 1) achieve positive pressure in the building under a majority of operating conditions, 2) avoid excessive ventilation, and 3) maintain air flow from dining area to kitchen, all while minimizing heating/cooling energy use and achieving acceptable dehumidification (<60% RH most of the time). Recommendations are presented to achieve these objectives.

Symbols and definitions

ACH50 - a measure of building airtightness, expressed as air changes per hour when the building is depressurized to 50 pascals (with respect to outdoors) by a calibrated fan.

air handler (AH) - in a forced air heating or cooling system, the cabinet which contains the distribution blower and may contain heat exchangers and filters.

air distribution system (ADS) - includes all building elements (ducts, plenums,s, cavities of the building structure, and mechanical closets) through which air is transferred between the conditioned space and the space conditioning equipment.

backdrafting - a condition where flow in a combustion vent pipe is reversed so that air moves down the vent and into the building. Combustion gases therefore discharge into the space.

l/s @ 50 - a measure of building airtightness, expressed as air flow rate (l/s) through leaks in the building envelope when the building is depressurized to 50 pascals by a calibrated fan.

exhaust air (EA) - air drawn from a building, typically to remove unwanted elements such as heat, humidity, odors, and combustion fumes.

HAC - heating and air conditioning

HVAC - heating, ventilating, and air conditioning.

infiltration - air flow across the building envelope, from outdoors to indoor, that is largely unintended. It may be driven by wind, temperature difference, duct leakage, return air imbalance, exhaust fans, clothes dryers, etc. Infiltration may act as a source of ventilation.

make-up air (MA) - air pushed into a building to replace EA drawn from the building, is typically unconditioned, delivered in proximity to the EA intake, and is normally operated simultaneously with the EA (both EA and MA controlled by the same on/off switch).

make-up air capture rate - fraction of MA captured by EA before mixing into the building air volume. If 90% of MA is directly captured by the EA, then the MA capture rate is 0.90.

outdoor air (OA) - air moved from outdoors to the return side of the ADS, by the suction of the ADS blower or by a dedicated blower, to provide ventilation to the conditioned space.

uncontrolled air flow - air moving across the building envelope or between zones or compartments of a building, where the pathways of flow, the direction of flow, and the origin of the air are unknown, unspecified, or unintended.

ventilation- the intentional transport of air from outdoors to indoors or the transport of indoor air to outdoors, generally to remove or dilute pollutants and improve indoor air quality.

wrt - = "with respect to". Pressures are expressed as pressure in one location with respect to another location (e.g. "restaurant pressure was -8.4 pascals wrt outdoors").

Introduction

Restaurants generally have large exhaust fans, and therefore have the potential to experience space depressurization and high ventilation rates. In hot and humid climates, this combination of space depressurization and a high ventilation rate can produce undesirable consequences related to energy waste, moisture problems, combustion safety, and poor indoor air quality. To avert these problems, MA may be added to offset EA. When properly applied, **MA** can greatly reduce space depressurization and ventilation rates. When properly controlled, **OA** can produce positive pressure while achieving acceptable thermal and humidity conditions.

Space depressurization is a function of building airtightness and net exhaust air (EAnet = EA - MA - OA; calculated based on the absolute value of air flows). By use of a chart, building pressure may be determined if airtightness and EAnet are known (Figure 1; based on chart by John Tooley and Neil Moyer of Natural Florida Retrofit, Inc.). This figure assumes n=0.65 for the equation Q = C(dP)n, where Q is EAnet (l/s), C is an air flow coefficient, dP is the indoor pressure wrt outdoors (pascals), and n is an air flow exponent. To the extent that n deviates from 0.65, the predicted pressures will be in error. **Example**; building airtightness is 2000 l/s @ 50 and EAnet is 1000 l/s. From Figure 1, find the intersection of 2000 l/s @ 50 and EAnet of 1000 l/s. The indicated pressure is -17.5 pascals. From the same figure, one can predict approximate building airtightness knowing EAnet and building pressure. **Example**; EAnet is 3500 l/s and building pressure is -10 pascals. From Figure 1, find the intersection of EAnet of 3500 and building pressure of 10 pascals. Indicated building airtightness is 10,000 l/s @ 50.

Building ventilation is a function of exhaust air, make-up air capture rate, and outdoor air, as defined by the following formulas.

Formula 1) If OA > (EA-MA), then ventilation (l/s) = OA plus non-captured MA (MA that escapes into the room and finds its way into the ADS).

Formula 2) If OA < (EA-MA), then ventilation (l/s) = (EA-MA) plus non-captured MA.

Two forms of uncontrolled air flow may also contribute to the building ventilation rate; duct leakage and unbalanced return air. Duct leakage, when it occurs outside the building air boundary, increases infiltration. If return duct leakage, then that leakage behaves like OA. To determine the effect of return leaks (drawing air from outside the building air boundary) on the building ventilation rate, add the return leak amount to OA and use formula 1 or 2. If supply duct leakage, then that leakage behaves like EA. To determine the effect of supply leaks (air spilling to outside the building air boundary) on the building ventilation rate, add the supply leak amount to EA and use formula 1 or 2. (Note that duct leaks that do not move air across the building air boundary do not influence the building ventilation rate.)

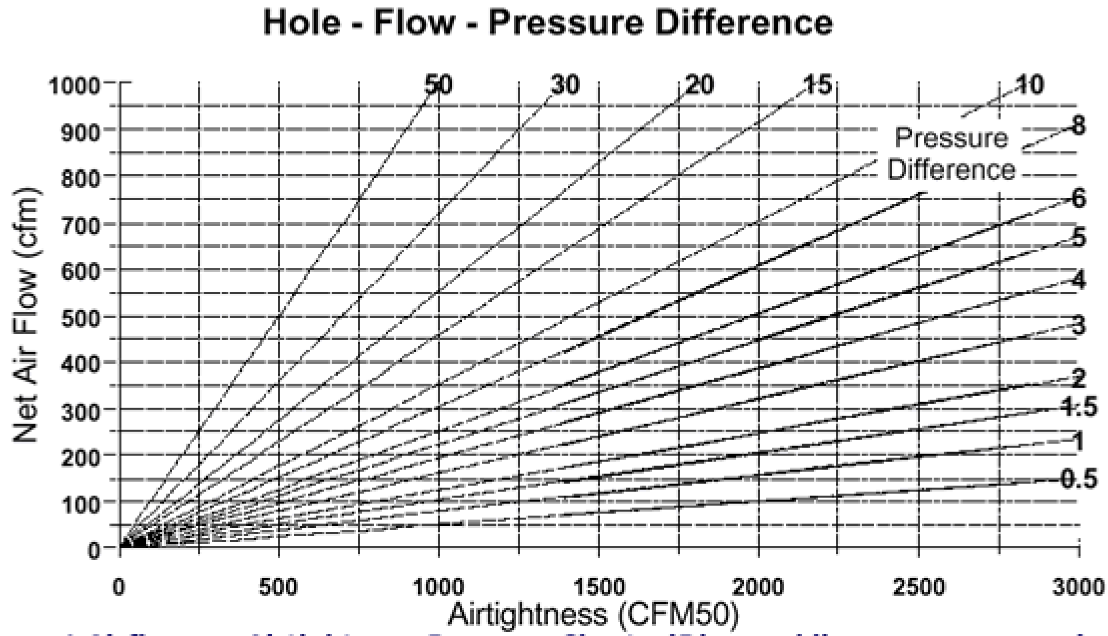

Figure 1 Airflow vs. Airtightness Pressure Chart. (Diagonal lines are pressure in pascals; chart assumes n=0.65.)

Unbalanced return air occurs when air flow from the conditioned space to the AH is restricted. This can be caused by closed interior doors when the return is located in a central zone, in which case the closed rooms go to a more positive pressure and the central zone goes to a more negative pressure. Positive pressure in the closed rooms pushes air out of the building and negative pressure in the central zone draws air into the building. Unbalanced return air can also occur when the ceiling space is used as a return plenum, fire walls subdivide this plenum, and the pathways through the fire walls are undersized or missing. Unbalanced return air can increase the building ventilation rate when the return air restriction causes one zone to be at positive pressure (wrt outdoors) and the other to be at negative pressure (wrt outdoors).

Research findings

Field testing was performed in 9 in central Florida restaurants (part of a sample of 70 small commercial buildings tested for uncontrolled air flow; Cummings et al., 1996), to characterize building air flow balance, airtightness, and pressures. Test data is presented in Table 1.

Table 1. Airtightness, ventilation, air flow, and pressure differential in 9 Florida restaurants.

restaurant type	floor area (m^2)	l/s @ 50	ACH50	vent rate* (ach)	exhaust (l/s)	make-up air (l/s)	outdoor air (l/s)	dP (pa)**
pizza	180.4	3810	31.2	1.9	1496	0	0	-13
subs	325.4	1021	3.9	5.3	2645	1520	684	-25
bar	223.0	3139	17.5	2.3	466	0	0	-1.8
golf club house	404.2	3977	11.6	1.9	1434	523	0	-6.1
chicken 1	293.7	3302	14.8	11.2	5006	2906	1063	-8.0
chicken 2	308.5	1741	7.7	5.9	4353	2412	590	-43
chinese	729.6	4771	8.2	2.2	3066	0	0	-4.6
hotel	1396.6	11002	7.6	1.7	6092	2428	385	-1.0
convenience store	401.3	5544	16.8	1.9	765	0	78	-1.8
average	473.6	4257	13.3	3.8	2814	1088	311	-11.6
*ventilation rate under normal building operation measured by tracer gas decay								
** space pressure wrt outdoors								

Ventilation rates

Ventilation rates averaged 3.8 ach under normal operation, ranging from 1.7 to 11.2 ach. Ventilation averaged 25.5 l/s per person in these 9 restaurants and ranged from 6.1 l/s per person to 82.1 l/s per person. ASHRAE Standard 62-1989 (ASHRAE 1989) calls for 10 l/s per person in restaurant dining areas, 15 l/s per person in bars and cocktail lounges, and 8 l/s per person in kitchen areas. Four of the 9 restaurants have bars or cocktail lounges. In 3 of these buildings, ventilation falls slightly below the recommended minimum during maximum occupancy. In most of the others, ventilation rates are excessive.

Depressurization caused by lack of make-up air

Four of the 9 restaurants have no MA, and 3 of the 4 have no OA. Consequently, these 4 restaurants experience negative pressure whenever the EA operates.

Depressurization caused by undersized make-up air

MA was provided in 5 of the 9 restaurants, but on average MA was only 51% of EA and OA was only 17% of EA (with all AHs operating and less if some were not operating). As a result, all 9 restaurants operated at negative pressures which ranged from -1.0 pascal to -43 pascals. The degree of depressurization is a function of the net exhaust air flow rate (EAnet = EA - MA - OA) and the airtightness of the building. The greater EAnet and the tighter the building envelope, the greater the building depressurization.

In all of these restaurants, the AHs do not run continuously. Rather they cycle on and off depending upon whether the thermostat calls for cooling or heating. Consequently OA is intermittent, turning on and off depending upon whether the AH is operating. Building pressure, therefore, varies as a function of which heating/cooling systems are operating.

In chicken restaurant 1, for example, each of the 4 AHs had OA and operated in on/off control depending upon whether the thermostat called for heating or cooling. When all AHs were operating, building pressure was -3 pascals. When AHs were turned off, incrementally one at time, pressure decreased to -6, -9, -13, and -18 pascals. Three consequences of this space depressurization were observed. First, mold growth was occurring behind vinyl wallpaper on exterior walls in this 9 month old building. The mold growth was occurring as humid outside air was drawn into wall cavities, accumulated on cool gypsum board surfaces inside the walls, and was prevented from drying to indoors by the vinyl wallpaper. Second, the gas water heater was backdrafting when building pressure was -9 pascals or greater causing combustion gases to spill into the occupied space. Third, on two occasions, the store owner reported water heater "flame rollout". These events occurred at closing time when the thermostats were changed to higher settings to reduce cooling energy use overnight. Flame roll-out occurs under the following conditions: room pressure is -18 pascals, the water heater is off, the vent pipe is backdrafting, air flow down the vent pipe pushes into the top of the flue (the flue is the vent stack inside the water heater), and then the water heater turns on. Since air is pushing down the flue, gas is pushed out of the burn chamber and combustion occurs partly outside the bottom portion of the water heater. On these two occasions, smoke poured from the water heater closet and staff had to extinguish the fire.

In chicken restaurant 2, two of the 4 AHs had OA. With both AHs operating, building pressure was -43 pascals. With both AHs off, building pressure was -63 pascals. In spite of the strong depressurization, combustion safety and mold problems were not identified. Backdrafting and flame roll-out from the water heater did not occur because it was located in an exterior closet, which was well connected to outdoors and isolated from indoors. When the building was at -63 pascals, the water heater closet was at neutral pressure wrt outdoors. The reason for no mold is uncertain, except that there is considerably less vinyl wallpaper compared to the other chicken restaurant, thereby allowing greater moisture migration through the building envelope.

In both of these restaurants, depressurization was exacerbated by the intermittency of OA. The reader may conclude, therefore, that the controls should be changed so that the AHs operate continuously when the EA operates. This would allow the OA to operate as a reliable form of MA. The problem with this strategy, however, is that continuous AH operation causes poor dehumidification performance, particularly with fixed-capacity cooling systems. This poor performance results from evaporation of moisture from the coil and drain pan during the periods when the compressor turns off (Khattar et al., 1987; Henderson et al., 1992). Depending upon the length of the compressor on-cycle, moisture collecting on the cooling coil may not have time to exit the pan before the compressor turns off and evaporation begins. Indoor relative humidity levels often increase by 10 percentage points or more as a result of continuous blower operation. In addition, moisture-laden outdoor air is supplied to the space when the compressors cycle off but the AHs continue to operate, further increasing indoor relative humidity during hot and humid weather conditions.

Depressurization due to dirty outside air and make-up air filters

In the sub sandwich restaurant, building air flow imbalance occurred as a result of dirty filters. These filters had not been cleaned or replaced in the 8 months since the building was constructed. At start-up, the HVAC contractor had demonstrated that the building was operating at positive pressure by showing smoke flowing out through a window. However, in the intervening months, building pressure had become progressively more negative (the authors surmise) as the filters became progressively more dirty. The building was operating at -25 pascals at the time it was tested. When the filters were cleaned or replaced, building pressure rose to -2 pascals. Two major consequences of depressurization were observed. First, the pilot light of the instantaneous gas water heater was repeatedly blown out by severe backdrafting in the water heater vent pipe resulting in unavailability of hot water. Restaurant staff had identified that opening an exterior door would allow lighting the pilot light and operation of the heater long enough to do washing. Second, sewer gas was entering the men's bathroom because of the -25 pascal pressure and a toilet that was improperly sealed to the sewer line.

In the convenience store, 765 l/s kitchen EA operated with no MA and limited OA. Intakes grills for the OA were located under an exterior eave unknown to store staff, and behind the grills were OA filters which had not been cleaned in years. The filters were clogged so total OA was only 77.9 l/s for combined cooling capacity of 61.5 kW (17.5 tons).

Solutions

There are several objectives of good restaurant air flow management; 1) achieve positive pressure in the building under a majority of operating conditions, 2) maintain flow of air from the dining area to the food preparation area, 3) avoid excessive ventilation, 4) minimize heating and cooling energy use, and 5) control the cooling system so that it achieves acceptable dehumidification (<60% RH most of the time). Achieving all of these objectives simultaneously is complicated. Following is one set of strategies to meet these objectives.

Positive pressure can be achieved by providing combined MA and OA greater than EA. As a first step, EA should be as small as possible while still meeting exhaust and ventilation requirements. As a second step, MA should be sized as large as possible, but normally not sized greater than 80% of EA. MA is sized at 80% or less of EA so that the food preparation area will be depressurized wrt to the dining area, air will flow from the dining area to the kitchen, and a large majority of the MA will be captured by the EA. To complete the building air flow balance, OA equal to 21% to 25% of EA should be provided to the dining area, thus enhancing air flow toward the kitchen.

Excessive ventilation is avoided by providing MA to a location proximate to both the cooking appliances and EA intake so that a large proportion of the MA is captured by the EA. Optimal design would indicate that the cooking appliances be located between the MA discharge and EA intake. MA discharge should be located as close as possible to the EA intake while still permitting capture of the vast majority of the heat, humidity, odors, grease, and combustion fumes associated with cooking, but not discharging onto restaurant staff or affecting pilot lights or burners. In hot and humid climates, care must be taken to avoid condensation of moisture contained in MA on interior surfaces.

HAC loads are minimized by minimizing ventilation (no more ventilation than is necessary), not conditioning MA, and optimizing design so that a maximum proportion of MA is captured by EA. [Note that modulation of EA flow in response to cooking intensity by means of fan speed controllers in conjunction with temperature and smoke density sensors is also an option.]

Finally, the cooling system control must meet two performance criteria: 1) provide OA to the space when the EA is operating and 2) control indoor temperature and relative humidity within acceptable limits. It is possible to have the AH blowers operate continuously whenever the EA is operating. In fact, it is not uncommon for commercial building AHs to operate continuously. However, this approach can seriously compromise the dehumidification performance of the cooling system as a result of evaporation of moisture from the coil and drain pan (see Section 2.3). One solution is to separate (to a large extent) space conditioning from ventilation, as follows.

Designate one heating/cooling system to treat OA. Its task is to provide conditioned OA to the dining area, and it will be controlled to operate simultaneously with EA and MA. While the AH blower will operate continuously in step with EA, the cooling compressor will cycle according to the requirements of the dining room thermostat. In order for the compressor to operate a large fraction of the time so that the OA will be cooled and dehumidified during hot and humid summer months, this designated OA unit can be controlled on the first stage of the thermostat. For example, if the thermostat setting for the dining area is 23.3°C, then the first stage operation could control the compressor for the designated OA unit to operate at say 22.2°C. On most warm and hot days of the year, the compressor for this OA unit would then operate most of the time, thereby providing good dehumidification. The other cooling systems serving the dining area would not have OA and they would be controlled on the second stage at a 23.3°C setting. [Note that this control is best achieved by use of a two-stage thermostat. Use of individual thermostats with each set at different temperatures may be ineffective because the thermostat settings may differ or change over time, causing the compressor of the designated OA system to not operate a large proportion of the time and therefore not effectively dehumidify the OA.]

Wrap up

Field research has identified problems in restaurants associated with air flow balance, space depressurization, and HVAC system control. These problems can be characterized as primary or secondary consequences. Primary consequences are space depressurization and excessive ventilation rates. These primary consequences, in turn, cause secondary consequences including moisture accumulation in building cavities, combustion safety problems associated with backdrafting and flame roll-out, drawing sewer gases into the building, high relative humidity, moisture damage to building materials, and mold/mildew growth.

A strategy has been presented for avoiding space depressurization and excessive ventilation. This involves providing unconditioned MA in proximity to the EA at about 80% of the EA flow rate and providing OA equal to about 21% to 25% of EA into the dining space, thus creating positive pressure in the building and enhancing air flow from dining area to kitchen. OA is provided by means of a dedicated OA heating/cooling system. The AH blower for this unit would operate continuously during EA operation. The compressor or heating source for this unit would cycle in response to the first stage of the thermostat so that the system would effectively dehumidify the OA during most hours of the year.

Acknowledgments

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