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Environmental characterization of a coffee processing workplace with obliterative bronchiolitis in former workers

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Abstract

Obliterative bronchiolitis in five former coffee processing employees at a single workplace prompted an exposure study of current workers. Exposure characterization was performed by observing processes, assessing the ventilation system and pressure relationships, analyzing headspace of flavoring samples, and collecting and analyzing personal breathing zone and area air samples for diacetyl and 2,3-pentanedione vapors and total inhalable dust by work area and job title. Mean airborne concentrations were calculated using the minimum variance unbiased estimator of the arithmetic mean. Workers in the grinding/packaging area for unflavored coffee had the highest mean diacetyl exposures, with personal concentrations averaging 93 parts per billion (ppb). This area was under positive pressure with respect to flavored coffee production (mean personal diacetyl levels of 80 ppb). The 2,3-pentanedione exposures were highest in the flavoring room with mean personal exposures of 122 ppb, followed by exposures in the unflavored coffee grinding/packaging area (53 ppb). Peak 15-min airborne concentrations of 14,300 ppb diacetyl and 13,800 ppb 2,3-pentanedione were measured at a small open hatch in the lid of a hopper containing ground unflavored coffee on the mezzanine over the grinding/packaging area. Three out of the four bulk coffee flavorings tested had at least a factor of two higher 2,3-pentanedione than diacetyl headspace measurements.

At a coffee processing facility producing both unflavored and flavored coffee, we found the grinding and packaging of unflavored coffee generate simultaneous exposures to diacetyl and 2,3-pentanedione that were well in excess of the NIOSH proposed RELs and similar in magnitude to those in the areas using a flavoring substitute for diacetyl. These findings require physicians to be alert for obliterative bronchiolitis and employers, government, and public health consultants to assess the similarities and differences across the industry to motivate preventive intervention where indicated by exposures above the proposed RELs for diacetyl and 2,3-pentanedione.

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Keywords

2,3-pentanedione; coffee roasting; diacetyl; exposures; flavorings; obliterative bronchiolitis

Introduction

Diacetyl has been shown to cause epithelial damage that can lead to obliterative bronchiolitis in animal models and workers exposed to it in the production of microwave popcorn, flavorings, and other foods such as cookie dough.[1,2] 2,3-Pentanedione, a diacetyl substitute, has proved no less hazardous in animal models,[1,3–4] but many flavor producers have used 2,3-pentanedione to meet client food producer requests for diacetyl-free flavors.[5] The coffee industry has diverse sources of potential exposure to alpha-diketones. Artifically flavoring coffee may entail using diacetyl- and 2,3-pentanedione-containing mixtures. In addition, roasting coffee beans naturally produces diacetyl and 2,3-pentanedione.[6,7] Grinding roasted coffee beans produces greater surface area for off-gassing of these and other chemicals.[8]

In 2012, investigators from the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation in a coffee processing plant with five cases of physician-diagnosed obliterative bronchiolitis among former workers.[9,10] Current workers had excess obstructive spirometric abnormalities and excessive shortness of breath on exertion in comparison to expected national rates.[10] This article presents an exposure characterization subsequent to changes made after recognition of former worker cases. These changes included the substitution of diacetyl with 2,3-pentanedione and addition of local exhaust ventilation in the flavoring room. Therefore, the conditions in 2012 were different than those under which the cases developed. Nonetheless, this article serves as a guide to evaluation of other coffee processing plants, which may have an unrecognized risk of occupational lung disease from exposures to diacetyl and 2,3-pentanedione, whether from off-gassing of unflavored coffee or adding flavoring chemicals to coffee.

Background

Facility and workforce

At the time of the NIOSH evaluation, the plant had approximately 85 employees and produced flavored and unflavored whole bean and ground roasted coffee and packaged some tea, largely for commercial consumers. The facility consisted of two stories of office space attached to a one-story steel industrial-style building that contained the production operations within several rooms. Many production area rooms were not completely isolated, i.e., the walls did not reach the ceiling and large curtained openings existed between rooms to facilitate forklift traffic. The flavoring room was kept under negative air pressure with respect to the other production areas, to prevent contamination of unflavored coffee with flavorings. Most employees worked 8-hr shifts; however, sometimes workers in the flavoring room worked 12-hr shifts, 3 or 4 days per week, and other workers worked overtime hours depending on the orders for that week.

Warehouse

The warehouse was separated into finished goods and greens (green coffee bean storage) areas by a wall with two breezeways at each end. Loading docks with overhead doors were located on the back wall of the warehouse. Workers known as greens unloaders transferred bags of green coffee beans onto pallets which were then moved and stacked in the greens warehouse via forklifts.

Roasting room

Workers known as greens dumpers emptied the green coffee beans into hoppers in the floor. The beans were automatically fed into a perforated cylinder within a large gas-fired coffee roaster. Workers known as roasters stood nearby to monitor the process. Throughout their shift, roasters took samples of roasted coffee beans to the quality control room to grind and evaluate the color.

Grinding/packaging room – unflavored coffee

The grinding/packaging room had six packaging lines for unflavored coffee, a mezzanine above the lines with hoppers for unflavored whole beans and ground coffee, a tea machine and associated mezzanine, and a hand packing station. Whole coffee beans delivered from the roasting room were stored in the mezzanine hoppers until ground or packed on the lines below. The ground coffee dropped into one of two grinding machines, and then was sent up to the mezzanine hoppers. Ground or whole coffee was placed in bags with exhaust valves to off-gas. Coffee to be packed in non-valved bags required a 12-hr off-gassing period in the mezzanine hoppers prior to packaging.

Flavored coffee production room

Coffee for flavoring was transported from the roasting room mezzanine level by elevators to hoppers in the flavoring room. Small batches of coffee off-gassed overnight. The next day, a worker scooped the coffee beans from a hopper into a bin on wheels and transported it to a flavoring mixing station. The worker scooped roasted coffee beans into open barrels mounted on a rotating rack. The liquid flavoring was weighed on a small scale and poured into the rotating barrel of roasted coffee beans. This process was repeated until all coffee beans were flavored. The worker stood nearby to monitor the process, break up clumps of coffee, and make sure the flavoring was evenly distributed. After mixing, the beans were manually emptied into storage containers on wheels. After all the coffee beans were flavored, they were transported via an enclosed bucket elevator to a hopper on the mezzanine for a 12-hr off-gassing before grinding. After grinding, they were transported back up to a hopper on the mezzanine for an additional 12-hr off-gassing before packaging.

Larger batches of hazelnut flavored coffee were more automated. The coffee was roasted and ground then flavored in a automated mixer that pumped the flavoring from a carboy directly onto the ground coffee. The flavored coffee was then transported up to the mezzanine via an enclosed bucket elevator to a hopper for a 12-hr off-gassing prior to packaging. The manual tasks included dumping the beans into an opening in the floor to be ground and filling the carboy with the appropriate flavoring.

In 2011, the company began an effort to use flavorings that did not contain diacetyl. By fall 2011, the company's predominant flavor no longer contained added diacetyl, according to company management.

Quality control room

Quality control technicians performed quality checks on the coffee during all steps of the production process. Throughout their shift, quality control technicians would go to other parts of the plant (such as the greens warehouse, grinding/packaging room, and flavoring room) to retrieve samples of coffee for quality checks.

For flavored coffee, quality control technicians opened flavored coffee bags, weighed the coffee on a scale, and brewed and tasted the coffee in the break room (located in the production support office area) to prevent contaminating the non-flavored coffee.

Offices

The non-production offices were in a two-story section of the building near the reception entrance to the plant. Several production support offices were located within the larger production area, adjacent to the grinding and packaging operation for unflavored coffee.

Worker mobility

Many employees did not spend all of their time in their company-designated department since their job duties entailed spending time in other areas of the plant. Some workers reported helping out in other departments, for example, with hand packing in the flavoring room or operating the packaging machines in the grinding/packaging room or flavoring room.

Ventilation system description

The flavoring room had two local exhaust ventilation systems, each with an exhaust fan on the outside wall. On one system, a canopy hood was located above the station where flavoring was pumped out of a large barrel into smaller one-gallon jugs. The one-gallon containers were stored in negative pressure ventilated cabinets above and below the bench used for weighing flavorings. An open-ended exhaust duct was located near the scale used to weigh out the small batch liquid flavorings, and the barrel flavoring station had a capture hood located just above the rolling barrels. The other local exhaust ventilation system in the flavoring room included a grinder machine ventilation hood enclosure similar to those in the grinding/packaging room, ductwork to the enclosed ventilated automated mixer, and a canopy hood above its flavoring carboy. Two additional fans in the wall exhausted air directly from the room. Cool air was provided to the room through two air-conditioning units: one recirculated the room air, and the other introduced fresh air from outside. The flavoring room ventilation systems were designed to maintain the area under negative pressure relative to the rest of the plant to prevent the flavorings from contaminating unflavored coffee.

The grinder machines in the grinding/packaging room were enclosed in sheet metal shrouds (or hoods), with access doors and plastic viewing windows, that were vented to an exhaust fan located adjacent to the roasting room wall fans.

The roasting room was taller than the adjacent warehouse and had two wall fans on the wall above the roof of the warehouse that exhausted air over the warehouse roof. Air from the roasters was directly exhausted through an afterburner system and then out of stacks on the roof above. Four air-conditioning units along the roasting room and adjacent maintenance shop outside wall provided makeup air. The production offices had air-conditioning units with fully recirculated air, while the non-production offices had a separate heating, ventilating, and air-conditioning system dedicated to that part of the building.

Methods

Sampling approach

The objectives were to identify exposures that may pose a risk for lung disease, including obliterative bronchiolitis and work-related asthma; to make recommendations aimed at reducing these risks; and to evaluate the workers' relative exposure levels to alpha-diketones and dust levels by job title and work area. The focus was on production jobs to better understand sources of alpha-diketones and dusts. Area samplers were placed in work areas to determine the background alpha-diketone concentrations compared to the worker personal sample concentrations while performing job tasks. Short-term exposure limit (STEL) area samples were taken to represent job tasks in areas where workers came into contact with large amounts of product such as the hoppers where roasted coffee off-gassed.

Headspace analysis of bulk materials

Four bulk liquid flavoring samples were collected in glass containers to investigate the volatile organic compound (VOC) emission potential of the material via headspace analysis. One milliliter (mL) of bulk material was placed into a sealed 40 mL amber volatile organic analysis vial with a polytetrafluoroethylene-lined septum where it stood for approximately 24 hr at room temperature (21°C) to allow for equilibration of VOCs between the liquid and the air. One to two mL of headspace air was injected into a 450 mL fused-silica lined evacuatedcanister and pressurized to approximately 1.5 times atmospheric pressure. The pressurized canister was placed on an Entech 7032A autosampler (Simi Valley, CA) which injected 200 mL of sample gas onto an Entech 7100A pre-concentrator attached to an Agilent 6890/5973 gas chromatograph/mass spectrometer system (Santa Clara, CA). Internal standards were added directly to the preconcentrator in order to quantify analyte concentrations. A 50 mL gas transfer of the following internal standards was used: bromochloromethane, 1,4-difluorobenzene and chlorobenzene-d5. The analyte concentrations were calculated in parts per million (ppm) by volume in the headspace based on the response factor of the closest internal standard. All headspace analyses were conducted in the Field Studies Branch Organics Laboratory at NIOSH (Morgantown, WV).

Diacetyl and 2,3-pentanedione air sampling

A total of 171 (59 personal/112 area) samples were collected according to the Occupational Safety and Health Administration (OSHA) sampling and analytical methods 1013/1016,[11,12] which are validated for diacetyl, acetoin (1013), and 2,3-pentanedione (1016). Two silica gel tubes (7 × 110-mm, 600 mg, 20/40 mesh, SKC Inc. 226–183, Eighty Four, PA) were connected in series by a small piece of tubing and inserted into a protective cover. The tubes were connected to a SKC Pocket Pump (SKC Inc., Eighty Four, PA) operated at 50 mL/min. The sampling setup was then attached to a worker in his/her personal breathing zone or to an area basket. For long-term sampling, we collected two consecutive 3-hr samples and calculated the time-weighted average (TWA) concentration from the two samples, assuming that the total 6-hour monitoring results reflected an 8-hr average exposure (i.e., the concentration was assumed to be the same for the 2-hr period not sampled). Two area STEL samples were collected in the same manner for 15 min at 200 mL/min.

The tubes were shipped cold and refrigerated upon receipt at the NIOSH contract laboratory until extraction and analysis. The front and back tubes were placed into separate 4 mL amber glass vials. The front glass fiber filter and glass wool plugs were discarded for each. The samples were chemically desorbed using 2 mL of 95% ethanol:5% water (ACS spectrophotometric grade) and shaken for 60 min. The samples were analyzed with OSHA method 1013/1016 using an HP 5890 (Agilent Technologies, Inc) GC/flame ionization detector (GC/FID) system with a Phenomenex ZB-1 capillary column (Torrance, CA) with dimensions 60 m × 0.32 mm × 1 μm and ultra-high purity (UHP) helium as carrier gas. 1 μL was injected into the GC inlet (250°C) with the oven temperature at 50°C (held for 5 min), followed by a ramp of 15°C/min to 170°C. Detector temperature was 300°C.

Acceptable quantitation limits for diacetyl were not reached using OSHA 1013 due to laboratory performance and a decreased sample volume (9 L instead of 10 L); therefore, sample extracts were subsequently derivatized using a modified OSHA 1012 method to increase sensitivity.[13] OSHA 1012 is validated for diacetyl and acetoin. A 0.5 mL sample aliquot was combined with 0.5 mL of derivatizing agent, O-(2,3,4,5,6-pentafluorobenzyl) hydroxylamine hydrochloride (PFBHA), and allowed to react for eight days before analysis with a GC/electron capture detector (GC/ECD). The derivatized extracts were analyzed with OSHA 1012 method using an HP 5890 (Agilent Technologies, Inc) (GC/ECD) system with an HP-5 capillary column (Agilent Technologies, Inc.) with dimensions 30 m × 0.32 mm × 0.25μm and UHP helium as carrier gas. 1 μL was injected into the GC inlet (220°C) with the oven temperature at 100°C (held for 1 min), followed by a ramp of 5°C/min to 200°C (held for 2 min), and an additional ramp at 20°C/min to 240°C. Detector temperature was 300°C.

Airborne analyte concentrations are reported in Tables 1–5 and in the text from the validated method with the greatest sensitivity for that analyte: OSHA 1012 for diacetyl and OSHA 1016 for 2,3-pentanedione. Additionally, for completeness, the unvalidated OSHA 1012 method for 2,3-pentanedione results are reported in Tables 6 and 7, since this method had greater sensitivity than the OSHA 1016 method and thus had fewer results below the limit of detection (LOD). Samples were corrected by batch based on laboratory control spike recoveries: 89% median recovery for diacetyl (range: 70–98%) and 78% for 2,3-

pentanedione (range: 70–91%). All sample extractions and analyses were conducted by Bureau Veritas North America (BVNA; Novi, MI).

Inhalable dust

During the industrial hygiene study, 25 personal and 101 area samples of inhalable dust were collected using the Institute of Occupational Medicine (IOM) Samplers (SKC Inc., Eighty Four, PA) containing PVC membrane filters with a 2 µm pore size operated at a sampling flow rate of 2.0 L/min for a minimum of 6 hours to achieve a TWA sample. They were then analyzed gravimetrically by BVNA according to the NIOSH Manual of Analytical Methods (NMAM) 500.[14]

Ventilation assessment

In November 2012, physical dimensions were taken of every production area, and approximate room volumes were calculated. Air flow measurements of supply vents and exhaust outlets were taken using either a TSI Incorporated, (St. Paul, MN), Accubalance Plus Model 8373 Air Capture Hood or a TSI VelociCalc Plus Model 8324 Rotating Vane Anemometer, depending on which was most appropriate. The complete set of ventilation measurements allowed the calculation of volumetric flow rates in cubic feet per minute (cfm) into and out of each area. Similar measurements were taken on the local exhaust ventilation systems to help assess the capture efficiency of each enclosure or hood. A Wizard Stick Handheld Fog Generator (Educational Innovations, Inc., Bethel, CT) or a larger Rosco Fog Machine Model 1600 (Rosco Laboratories, Inc., Stamford, CT) was used to visualize air movement as an indication of pressure differentials between various areas of the plant and to visualize airflow patterns in and around local exhaust ventilation hoods to investigate whether contaminant sources were effectively captured and removed by the ventilation system. Pressure differential measurements using a Model DM1 Digital Micro-Manometer (Infiltec, Waynesboro, VA) were taken to determine the predominant direction of air migration between production rooms. Total and outdoor air exchange rates for each area in the production facility were estimated using these data.

Data analysis

Analyses were performed using SAS 9.2 and JMP 10 (SAS Institute; Cary, NC). Summary statistics and box plots for OSHA methods 1012 and 1016 were created by job title and location. Since a large fraction of some area and personal samples were below the LOD the Tobit regression model, which uses the maximum likelihood estimate method,[15] was used to estimate the mean and variance of the natural log transformed data. Using these estimate, the minimum variance unbiased estimator (MVUE) of the arithmeticmean of the lognormally distributed data was calculated for diacetyl, 2,3-pentanedione, and inhalable dust exposures. The arithmetic mean is the desired measure of central tendency for estimating exposure in chronic disease investigations,[16] and the MVUE is the preferred estimator of the mean when the data are log-normally distributed.[17]

Results

Headspace analysis of bulk materials for apha-diketones

Diacetyl was identified in the headspace of all four flavorings analyzed. 2,3-Pentanedione and 2,3-hexanedione were found in three of the four flavorings (Table 1). Concentrations of 2,3-pentanedione were approximately 10–50 times higher than diacetyl in the three samples in which diacetyl and 2, 3-pentanedione were detected.

Diacetyl and 2,3-pentanedione air sampling

Time-weighted average area air samples for diacetyl and 2,3-pentanedione were highest in the grinding/packaging room and flavoring room (Tables 2 and 3). The flavoring room (90 ppb diacetyl, 151 ppb 2,3-pentanedione) had higher estimated mean 2,3-pentanedione air concentrations than the grinding/packaging room (103 ppb diacetyl, 63 ppb 2,3-pentanedione), while diacetyl concentrations were similar in the two areas. The production office area (61 ppb diacetyl, 32 ppb 2,3-pentanedione) adjacent to the grinding/packaging room had next highest mean concentrations followed by the roasting room (21 ppb diacetyl, 7 ppb 2,3-pentanedione). Other areas inside the facility had lower mean area concentrations of both diacetyl and 2,3-pentanedione (Tables 2 and 3).

Personal sample estimated mean concentrations were highest for employees in the grinding/packaging and flavoring rooms (Tables 2, 3, and 6) with the same pattern of similar estimated mean diacetyl concentrations in the grinding/packaging area (93 ppb) than the in the flavoring room (80 ppb) and lower 2,3-pentanedione levels in the grinding/packaging area (53 ppb) than the flavoring room (122 ppb). Employees in the production offices (77 ppb diacetyl, 20 ppb 2,3-pentanedione) had the next highest mean personal concentrations, followed by the all-over workers (59 ppb diacetyl, 39 ppb 2,3-pentanedione) and housekeeping (n = 1, actual values 54 ppb diacetyl, 18 ppb 2,3-pentanedione). These were followed by those in the roasting room (26 ppb diacetyl, 7 ppb 2,3-pentanedione) and quality control room (23 ppb diacetyl, 11 ppb 2,3-pentanedione). For these last areas, mean personal exposures were higher than those suggested by area measurements, with a personal diacetyl TWA in a nonproduction office worker of 7 ppb diacetyl.

The estimated mean personal exposures by job title demonstrated variation within work areas, particularly in the grinding/packaging area (Tables 4, 5, and 7). In the grinding/packaging area, grinders had nearly double the diacetyl concentrations (n = 2, 151 ppb) than the other job titles of packaging operator/grinder and hand packer, where estimated mean personal samples ranged from 80–91 ppb. In the flavoring room, in contrast, different job titles had personal estimated mean diacetyl exposures that were similar, from 71–89 ppb. For estimated mean personal 2,3-pentanedione exposures, grinders again had substantially higher exposures than other job title categories (90 ppb vs. 42−59 ppb for other job titles) in the grinding/packaging area. In the flavoring room, there was less variation in estimated mean personal exposures by job title, which ranged from 129–133 ppb for packers, packaging machine operators/grinders and mixers, with handpackers and flavor specialists having slightly lower means of 90–116 ppb.

Using OSHA method 1012 for reanalysis of 2,3-pentanedione samples to overcome the high proportions of samples that were below LOD, we found higher 2,3-pentanedione concentrations in estimated mean area, personal, and job titles measurements (Tables 6 and 7). The relative relations of diacetyl and 2,3-pentanedione by location and job title remained the same as with the less sensitive OSHA method 1016 results (Tables 3 and 5).

Packaging machine operators were required to check the bin levels periodically to maintain an adequate level of material for packaging and to dislodge any clogs. Small hatches within the lids of the bins were used for these purposes. A 15-min sample at the open hatch of a grinding/packaging room mezzanine hopper holding ground coffee had concentrations of 14,300 ppb diacetyl and 13,800 ppb 2,3-pentanedione. A 15-min sample at the open hatch of an adjacent empty hopper over the same packaging line had 628 ppb diacetyl and 475 ppb 2,3-pentanedione.

Dust

The estimated mean inhalable dust area sample concentrations were highest in the roasting room (0.70 milligrams per cubic meter (mg/m^3)) (Table 8). The estimated mean inhalable dust personal sample results were similar to the area sample results, but the warehouse greens unloaders showed the highest estimated mean concentrations (4.4 mg/m^3) followed by personal samples in the roasting room (1.9 mg/m^3).

Ventilation assessment

Table 9 summarizes the values used for the estimated air exchange rates which provide an indication of how compounds of concern could be diluted and eventually exhausted from the facility. The measured difference of 8,480 cfm between total exhaust and supply air represents the amount of air entering the plant through open doors or windows, or around doors and through other leaks in the building. This was demonstrated by the sudden rush of air into the warehouses when any of the warehouse doors were opened. Given that the amount of combustion air used in the afterburners was impossible to measure, it is likely the difference between exhaust and supply air was even higher than measured.

The results of the differential pressure measurements indicated general air flow patterns throughout the facility. The micromanometer measurements showed that the finished goods and greens warehouse areas were neutral to one another. Air flowed slightly from the grinding/packaging room into the finished goods warehouse and roasting room, and air flowed slightly from the roasting room into the greens warehouse. As intended to prevent contamination of unflavored coffee with flavorings, air flowed from the grinding/packaging room into the flavoring room.

During the fog testing of the new grinding machine enclosures in the grinding/packaging room and flavoring room, significant leakage was observed from all the grinding machine enclosures, especially at the unsealed opening on the top where the feed chutes and ventilation duct passed through, around the doors and windows, and at the corrugated sheet metal joints. Fog testing also showed poor capture by the local exhaust hood over the roasters and stove in the quality control room.

Discussion

Although the sentinel cases of obliterative bronchiolitis were attributed to historical diacetyl exposures in the flavoring room,[9] our investigation raised an additional source of exposure to diacetyl (and other alpha-diketones) in coffee processing. These chemicals are formed during the roasting process and released during off-gassing. This release is intensified as a result of grinding.[6–8] Indeed, diacetyl levels were as high in the area in which roasted coffee was ground and packaged, and this area was under positive pressure in relation to the flavoring room. Although the company had requested that its flavoring suppliers eliminate diacetyl from the flavorings, our analyses of head space samples from bulk samples showed that they continued to contain some diacetyl, as well as other alpha-diketones that are being used as diacetyl substitutes. Headspace analysis showed that for three of the flavorings tested, 2,3-pentanedione concentrations were one to two orders higher than diacetyl.

In animal models, 2,3-pentanedione did not prove to be a safe alternative to diacetyl.(3–4) The toxicity of diacetyl and 2,3-pentanedione for respiratory epithelium likely reflects their common alpha-diketone structure, and it would be prudent to consider concurrent exposure to both chemicals as at least additive. Consistent with the headspace measurements, the higher concentrations of 2,3-pentanedione in the flavoring room than in other areas likely had flavoring sources, supplemented by off-gassing of the roasted coffee itself. In contrast, the source of diacetyl and 2,3-pentanedione concentrations in the unflavored grinding/packaging room was undoubtedly the enhanced off-gassing of the chemicals associated with grinding of recently roasted unflavored coffee beans.[8] The finding of many ppm levels of these two chemicals in 15-min samples collected on the mezzanine in hoppers storing roasted and ground unflavored coffee is consistent with this off-gasing source. Even empty hoppers on the mezzanine had hundreds of ppb levels of these two chemicals in short-term sampling, and the proposed STELs are 25 ppb and 31 ppb for diacetyl and 2,3-pentanedione, respectively. When the sum of diacetyl and 2,3-pentanedione concentrations are examined by work area, the exposures encountered by grinding/packaging workers were equivalent to the exposures in the flavoring room at the rate of production during the time of our study. Levels of diacetyl and 2,3-pentanedione in the air will be affected by production rates, thus may differ with different production conditions. Our team of investigators was unable to differentiate health risk between exposure to flavoring-related chemicals and the same chemicals produced in the roasting of coffee.[10]

Whether other coffee processing facilities have worker risk of obliterative bronchiolitis is currently unknown. Certainly, this facility had exposures to both diacetyl and 2,3-pentanedione from flavored and unflavored coffee that were each many times the proposed NIOSH RELs of 5 ppb (diacetyl) and 9.3 ppb (2,3-pentanedione).[1] The company had taken measures, which we substantiated by pressure and ventilation studies, to prevent the contamination of unflavored coffee with flavorings used in flavored coffee by keeping the flavoring room under negative pressure with respect to the rest of the facility. However, without suspecting that similar levels of alpha-diketones were generated in the processing of unflavored ground coffee, the company had not isolated the grinding/packaging area from other workers who need not have had exposures from this alternate source, including the workers in the flavoring room. The air handling units serving the production offices were recirculating air from the the grinding/packaging room. The production office corridor area served as the personal protective equipment donning area and the passageway from the nonproduction offices and quality control room to the production areas and warehouse. Indeed, the grinding/packaging area was under positive pressure even in relation to the warehouse areas and the roasting room.

The majority of dust sample results were at or below the limit of detection, except in the roasting room. All of the dust sample results were below the OSHA standard for total dust concentrations of 15 mg/m^3 for an 8-hour shift[18] and the American Conference of Governmental Industrial Hygienists (ACGIH) recommendation of 10 mg/m^3 for an 8-hr shift for particulates not otherwise regulated.[19] Roasting room workers reported significantly higher prevalence of irritative symptoms in the previous 12 months, such as sinus symptoms, burning eyes, wheezing, and having trouble with breathing,[10] in contrast to workers with much higher exposures to alpha-diketones in the grinding/packaging and flavoring rooms. Symptoms of obliterative bronchiolitis from alpha-diketone exposure are seldom present in temporal relation to the workday, since the epithelial damage is irreversible. In contrast, symptoms related to irritation are commonly associated with the workday and improve after work and on weekends. The unique exposures of roasters were to particles from dumping of coffee beans and smoke generated from roasting. These exposures may be responsible for work-related symptoms.

Ventilation inadequacies resulted in a production office area that had production-level exposures; a respirator donning area that had production-level exposures; and a flavoring room that had air being pulled into it from the area that showed the highest levels of diacetyl. This design is unfavorable because it results in the exposure of workers that either do not work in production or work in areas with significantly lower levels of alpha-diketones. This environmental characterization demonstrates priorities for intervention to lower risk of occupational lung disease in this facility, such as respiratory protection with appropriate protection factors, properly designed and operating exhaust ventilation, new supply air for some functional spaces, and administrative controls to limit numbers of workers in particular areas.

While the cases of lung disease in former workers likely occurred under different exposure conditions, the exposures documented in November 2012 still pose a risk of lung disease. With the very high intermittent exposures of workers inspecting hoppers of roasted beans and ground coffee on the mezzanines of both unflavored and flavored coffee production areas, respiratory protection is necessary with powered air-purifying respirators with an assigned protection factor of 1000. Peak exposures to diacetyl are suspected to be hazardous, despite relatively low-level average exposures, as occurred in quality control workers in microwave popcorn production.[20] Engineering controls are required to provide uncontaminated air to production office workers and others outside of the grinding/packaging areas. Exhaust ventilation is needed for the roasters to decrease smoke and at dumping operations, for the mezzanine hoppers, grinders, and packaging areas, and in the flavoring room. Tightening the enclosures around the grinders and improving the performance of existing local exhaust ventilation could result in lower worker exposures. However, it is likely that with diacetyl and 2,3-pentanedione effluents at high concentrations from these production areas, make-up air and balancing will require additional ventilation engineering attention. Finally, we have suggested ongoing medical surveillance of workers in attempts to prevent additional lung disease.[10] These recommendations require consideration in other coffee processing facilities until additional medical surveys and environmental characterizations occur across the industry to assess whether this environmental investigation has typical or atypical findings. At the current time, NIOSH is conducting health hazard evaluations in other coffee processing facilities.

Conclusion

At a coffee processing facility producing both unflavored and flavored coffee, we found the grinding and packaging of unflavored coffee generate simultaneous exposures to diacetyl and 2,3-pentanedione that were well in excess of the NIOSH proposed RELs and similar in magnitude to those in the areas using a flavoring substitute for diacetyl. These findings require physicians to be alert for obliterative bronchiolitis and employers, government, and public health consultants to assess the similarities and differences across the industry to motivate preventive intervention where indicated by exposures above the proposed RELs for diacetyl and 2,3-pentanedione.

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Table 1

Alpha-diketones in headspace of flavoring bulk samples.

	Flavor A		Flavor B		Flavor C		Flavor D	
Chemical	**ppb**	**μg/mL bulk**	**ppb**	**μg/mL bulk**	**ppb**	**μg/mL bulk**	**ppb**	**μg/mL bulk**
Diacetyl	1.97×10^4	1.3	2.62×10^3	0.18	5.90×10^4	4.0	1.05×10^4	0.70
2,3-Pentanedione	1.04×10^6	83	—	—	5.29×10^5	42	5.06×10^5	41
2,3-Hexanedione	8.2×10^4	7.5	—	—	4.25×10^4	3.9	5.55 × 104	5.1

ppb = parts per billion; μg/mL = microgram per milliliter of bulk sample; "—"= not detected.

Table 2

Time-weighted average diacetyl (OSHA Method 1012) area and personal air sampling results by location.

Sample Type	Location[a]	N	N <LOD	Mean (ppb)	Geometric mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Area	Warehouse	20	0	10.7	10.0	1.5	4.8	16.6
	Roasting Room	22	0	20.9	19.4	1.5	95	50.6
	Grinding/Packaging Room[b]	21	0	102.8	99.7	1.3	67.9	247.2
	Flavoring Room	20	0	90.3	86.7	1.3	44.0	144.0
	Quality Control Room	4	0	7.6	7.5	1.2	5.5	9.5
	Maintenance Shop	2	0	6.4	5.9	1.7	3.5	10.2
	Offices-Production Area	8	0	61.4	59.4	1.3	33.8	93.4
	Offices-Nonproduction	6	0	3.9	3.8	1.2	2.6	4.9
	Outside	4	0	3.4	3.2	1.5	1.9	4.8
	Outside-Flavoring Room LEV Exhaust	4	0	22.4	19.0	2.0	7.2	46.5
Personal	Warehouse	9	0	8.0	7.6	1.4	4.3	11.7
	Roasting Room	9	0	25.9	24.9	1.3	15.1	40.1
	Grinding/Packaging Room	16	0	93.0	91.1	1.2	75.4	166.0
	Flavoring Room	12	0	79.6	78.4	1.2	52.6	96.3
	Quality Control Room	3	0	23.1	21.7	1.6	11.7	31.3
	Offices-Production	3	0	77.3	70.9	1.7	39.7	139.5
	Offices-Nonproduction	1	0	—	—	—	7.2	7.2
	Housekeeping	1	0	—	—	—	54.1	54.1
	All Over	5	0	58.7	58.0	1.2	49.2	80.1

LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; N = number of samples; LEV = local exhaust ventilation; ppb = parts per billion. “—”= not detected or fewer than two measurements above the detection limit. OSHA = Occupational Safety and Health Administration.

[a] Offices-nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b] Only unflavored coffee production occurs here.

Table 3

Time-weighted average 2,3-pentanedione (OSHA Method 1016) area and personal air sampling results by location.

Sample Type	Location[a]	N	N<LOD	Mean (ppb)	Geometric mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Area	Warehouse	20	19	—	—	—	<5.0	6.0
	Roasting Room	22	11	7.0	5.5	2.0	<5.3	26.8
	Grinding/Packaging Room[b]	21	0	62.6	55.9	1.6	23.0	190.6
	Flavoring Room	20	0	151.2	141.1	1.5	48.7	273.1
	Quality Control Room	4	4	—	—	—	<4.9	<7.0
	Maintenance Shop	2	2	—	—	—	<5.2	<5.6
	Offices-Production	8	0	32.4	29.4	1.6	9.9	46.2
	Offices-Nonproduction	6	6	—	—	—	<5.3	<5.6
	Outside	4	4	—	—	—	<4.9	<5.5
	Outside Flavoring Room LEV Exhaust	4	0	71.6	47.3	3.0	14.5	254.1
Personal	Warehouse	9	9	—	—	—	<5.2	<5.9
	Roasting Room	9	6	6.9	4.8	2.5	<6.0	15.8
	Grinding/Packaging Room[b]	16	0	52.5	46.9	1.6	17.9	133.6
	Flavoring Room	12	0	121.6	117.1	1.3	79.6	199.0
	Quality Control Room	3	1	11.4	9.6	2.1	<5.4	15.8
	Offices-Production	3	0	19.5	16.7	2.0	9.5	44.8
	Offices-Nonproduction	1	1	—	—	—	<5.6	<5.6
	Housekeeping	1	0	—	—	—	18.0	18.0
	All Over	5	0	38.7	38.4	1.1	31.7	45.0

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; LEV = local exhaust ventilation; ppb = parts per billion. "—"= not detected or less than two measurements above the detection limit; "<" = less than limit of detection. OSHA = Occupational Safety and Health Administration.

[a] Offices-Nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b] Only unflavored coffee production occurs here.

Table 4

Time-weighted average diacetyl (OSHA Method 1016) personal air sampling results by job title.

Location[a]	Job Title	N	N <LOD	Mean (ppb)	Geometric Mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Warehouse	Warehouse Clerk	2	0	8.1	7.7	1.5	5.1	11.7
	Shipping/Receiving	3	0	6.7	6.3	1.6	4.3	11.7
	Greens Unloader	4	0	8.7	8.7	1.1	8.1	9.1
Roasting Room	Roaster	6	0	29.1	28.3	1.3	18.4	40.1
	Dumper	3	0	19.6	19.4	1.2	15.1	22.4
Grinding/Packaging[b]	Tea Machine Operator	1	0	—	—	—	78.1	78.1
	Packer	7	0	85.8	85.7	1.1	79.8	93.6
	Packaging Operator/Grinder	3	0	90.8	90.5	1.1	80.8	103.9
	Hand Packer	3	0	80.0	79.8	1.1	75.4	89.0
	Grinder	2	0	150.8	150.4	1.1	136.2	166.0
Flavoring Room	Packer	2	0	87.5	87.3	1.1	79.0	96.3
	Packaging Operator/Grinder	2	0	70.5	69.2	1.3	52.6	91.0
	Mixer	3	0	81.0	80.7	1.1	68.8	88.3
	Hand Packer	2	0	89.3	89.3	1.0	88.9	89.7
	Flavor Specialist	3	0	71.2	70.7	1.2	61.0	85.6
Quality Control Room	Quality Control Technician	3	0	23.1	21.7	1.6	11.7	31.3
Offices-Production	Production Supervisor	1	0	—	—	—	64.3	64.3
	Plant Manager	1	0	—	—	—	139.5	139.5
	Maintenance Manager	1	0	—	—	—	39.7	39.7
Offices-Nonproduction	QA/Safety Manager	1	0	—	—	—	7.2	7.2
Housekeeping	Housekeeper	1	0	—	—	—	54.1	54.1
All Over	Material Handler	2	0	68.5	68.0	1.2	57.8	80.1
	Maintenance Technician	3	0	52.2	52.1	1.1	49.2	57.2

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; ppb = parts per billion. Note: For sample sizes of one, the result of the single sample is presented in the min/max columns. "—"= not detected or less than two measurements above the detection limit. OSHA = Occupational Safety and Health Administration.

[a] Offices-Nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b] Only unflavored coffee production occurs here.

Table 5

Time-weighted average 2,3-pentanedione (OSHA Method 2016) personal air sampling results by job title.

Location[a]	Job Title	N	N <LOD	Mean (ppb)	Geometric Mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Warehouse	Warehouse Clerk	2	2	—	—	—	<52	<5.9
	Shipping/Receiving	3	3	—	—	—	<5.3	<5.5
	Greens Unloader	4	4	—	—	—	<52	<5.6
Roasting Room	Roaster	6	3	9.1	7.3	2.1	<6.0	15.8
	Dumper	3	3	—	—	—	<6.4	<7.1
Grinding/Packaging[b]	Tea Machine Operator	1	0	—	—	—	45.7	45.7
	Packer	7	0	42.9	39.7	1.5	21.6	64.5
	Packaging Operator/Grinder	3	0	41.7	38.0	1.7	17.9	57.6
	Hand Packer	3	0	58.6	58.1	1.2	46.0	65.6
	Grinder	2	0	89.8	85.5	1.6	54.7	133.6
Flavoring Room	Packer	2	0	130.8	130.8	1.0	129.6	132.0
	Packaging Operator/Grinder	2	0	128.7	122.9	1.5	79.6	189.6
	Mixer	3	0	133.3	127.4	1.5	80.4	199.0
	Hand Packer	2	0	90.3	90.1	1.1	82.6	98.3
	Flavor Specialist	3	0	115.5	115.5	1.0	113.8	117.7
Quality Control Room	Quality Control Technician	3	1	11.4	9.6	2.1	<5.4	15.8
Offices-Production	Production Supervisor	1	0	—	—	—	44.8	44.8
	Plant Manager	1	0	—	—	—	10.8	10.8
	Maintenance Manager	1	0	—	—	—	9.5	9.5
Offices-Nonproduction	QA/Safety Manager	1	1	—	—	—	<5.6	<5.6
Housekeeping	Housekeeper	1	0	—	—	—	18.0	18.0
All Over	Material Handler	2	0	37.7	37.7	1.1	35.6	39.8
	Maintenance Technician	3	0	39.2	39.0	1.2	31.7	45.0

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; ppb = parts per billion. "—" = not detected or less than two measurements above the detection limit; "<" = less than limit of detection. OSHA = Occupational Safety and Health Administration.

[a] Offices-Nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b] Only unflavored coffee production occurs here.

Table 6

Time-weighted average 2,3-pentanedione (OSHA Method 1012) area and personal air sampling results by location at coffee processing facility, November 2012.

Sample Type	Location[a]	N	N <LOD	Mean (ppb)	Geometric mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Area	Warehouse	20	0	9.1	7.9	1.7	3.0	16.6
	Roasting Room	22	0	20.2	16.5	1.9	2.5	58.6
	Grinding/Packaging Room[b]	21	0	103.4	92.7	1.6	43.0	327.4
	Flavoring Room	20	0	178.5	162.8	1.6	67.0	325.0
	Quality Control Room	4	0	10.5	9.3	1.8	4.2	16.6
	Maintenance Shop	2	0	6.7	6.7	1.1	6.4	7.1
	Offices-Production Area	8	0	62.2	59.5	1.4	34.2	83.3
	Offices-Nonproduction	6	0	4.7	4.6	1.3	3.3	7.2
	Outside	4	0	3.3	3.2	1.1	2.8	3.9
	Outside Flavoring Room LEV Exhaust	4	0	99.5	65.4	3.0	17.8	322.0
Personal	Warehouse	9	0	6.0	5.5	1.6	2.9	10.8
	Roasting Room	9	0	20.5	18.2	1.7	8.8	42.7
	Grinding/Packaging Room[b]	16	0	86.1	80.2	1.5	34.5	183.3
	Flavoring Room	12	0	143.1	138.9	1.3	100.7	232.4
	Quality Control Room	3	0	23.3	20.3	1.9	8.2	34.4
	Offices-Production	3	0	54.1	48.3	1.8	21.0	73.7
	Offices-Nonproduction	1	0	—	—	—	14.7	14.7
	Housekeeping	1	0	—	—	—	47.2	47.2
	All Over	5	0	66.3	65.1	1.2	49.5	85.2

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; LEV = local exhaust ventilation; ppb = parts per billion. "—"= not detected or less than two measurements above the detection limit. OSHA = Occupational Safety and Health Administration.

[a]Offices-Nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b]Only unflavored coffee production occurs here.

Table 7

Time-weighted average 23-pentanedione (OSHA Method 1012) personal air sampling results by job title.

Location[a]	Job Title	N	N <LOD	Mean (ppb)	Geometric Mean (ppb)	Geometric Standard Deviation	Minimum (ppb)	Maximum (ppb)
Warehouse	Warehouse Clerk	2	0	5.4	5.3	1.3	4.0	7.0
	Shipping/Receiving	3	0	4.6	4.3	1.6	2.9	7.9
	Greens Unloader	4	0	7.3	6.8	1.6	3.6	10.8
Roasting Room	Roaster	6	0	25.2	22.9	1.6	10.7	42.7
	Dumper	3	0	11.6	11.4	1.2	8.8	14.9
Grinding/Packaging[b]	Tea Machine Operator	1	0	—	—	—	70.3	70.3
	Packer	7	0	71.7	67.4	1.5	34.5	108.7
	Packaging Operator/Grinder	3	0	80.9	77.9	1.4	48.4	102.7
	Hand Packer	3	0	98.4	98.4	1.1	93.5	105.2
	Grinder	2	0	126.8	121.7	1.5	80.8	183.3
Flavoring Room	Packer	2	0	155.6	155.3	1.1	140.7	171.3
	Packaging Operator/Grinder	2	0	149.6	147.3	1.3	115.1	188.6
	Mixer	3	0	141.4	134.6	1.5	100.7	232.4
	Hand Packer	2	0	117.9	117.3	1.1	102.8	133.9
	Flavor Specialist	3	0	144.3	143.3	1.2	121.7	171.6
Quality Control Room	Quality Control Technician	3	0	23.3	20.3	1.9	8.2	34.4
Offices-Production Area	Production Supervisor	1	0	—	—	—	72.9	72.9
	Plant Manager	1	0	—	—	—	73.7	73.7
	Maintenance Manager	1	0	—	—	—	21.0	21.0
Offices-Nonproduction	QA/Safety Manager	1	0	—	—	—	14.7	14.7
Housekeeping	Housekeeper	1	0	—	—	—	47.2	47.2
All Over	Material Handler	2	0	72.6	72.5	1.1	67.2	78.3
	Maintenance Technician	3	0	61.8	60.6	1.3	49.5	85.2

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; ppb = parts per billion. "—" = not detected or less than two measurements above the detection limit. OSHA = Occupational Safety and Health Administration.

[a]Offices-Nonproduction also includes reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room air samples; grinding/packaging room category also includes the tea machine and hold room air samples; all over includes material handlers and maintenance technicians.

[b]Only unflavored coffee production occurs here.

Table 8

IOM gravimetric air sampling results by location.

Sample Type	Location	N	<LOD <LOD	Mean (mg/m^3)	Geometric mean (mg/m^3)	Geometric Standard Deviation	Minimum (mg/m^3)	Maximum) (mg/m^3)
Area	Warehouse	20	16	0.192	0.131	2.47	<0.26	0.75
	Roasting Room	20	3	0.704	0.611	1.73	<0.28	1.24
	Grinding/Packaging Room[a]	21	14	0.254	0.219	1.76	<0.27	0.72
	Flavoring Room	19	16	0.191	0.169	1.67	<0.27	0.46
	Quality Control Room	4	3	—	—	—	<0.27	0.41
	Maintenance Shop	2	1	—	—	—	<0.28	0.50
	Offices-Production	6	5	—	—	—	<0.26	0.38
	Offices-Nonproduction[b]	7	6	—	—	—	<0.27	0.36
	Outside Flavoring Room LEV Exhaust	3	1	0.296	0.295	1.12	<0.28	0.34
Personal	Warehouse (Greens Unloaders)	10	2	4.39	1.07	6.55	<0.27	14.93
	Roasting Room	8	0	1.91	1.84	1.34	0.95	2.71
	Grinding/Packaging Room[b]	3	1	0.443	0.424	1.44	<0.32	0.59
	Flavoring Room	1	0	—	—	—	1.11	1.11
	Quality Control Room	1	1	—	—	—	—	—
	All Over	2	0	0.293	0.293	1.07	0.27	0.31

N = number of samples; LOD = limit of detection; Mean = minimum variance unbiased estimator of the arithmetic mean; mg/m^3 = milligram per cubic meter. "—" = not detected or less than two measurements above the detection limit; "<" = less than limit of detection.

[a]Only unflavored coffee production occurs here.

[b]Offices-nonproduction also includes the reception area; warehouse includes the greens warehouse and finished goods warehouse; offices-production category also includes corridor, break room, and maintenance room; grinding/packaging room category also includes the tea machine and hold room.

Table 9

Ventilation measurements classified by location.

Plant Location[a]	Area of Space (ft^2)	Volume of Space (ft^3)	Typical Number of Workers in Space	Exhaust Air to Outside (cfm)	ACH based on Exhaust Air	Outdoor Air Supply (cfm)	ACH based on Outdoor Air Intake
Roasting room	6430	208,200	9	8970[b]	2.6	8760	2.5
Grinding/packaging room	8770	351,480	14	2890	0.5[c,d]	0[c]	0.0
Flavoring room	2280	83,210	8	6970[f]	5.0[e]	1590	1.1
Greens warehouse	19,930	398,600	0	0[c]	0.0[g]	0[g]	0.0
Finished goods warehouse	19,790	397,160	4	0[c]	0.0[g]	0[g]	0.0
TOTAL	57,200	1,438,650	35	18,830	8.1	10,350	3.6

[a] Note: ft^2 = square feet; ft^3 = cubic feet; cfm = cubic feet per minute; ACH = air exchange per hour.

[b] Does not include combustion air used by afterburners.

[c] A zero measurement indicates that no mechanical systems for air movement were present, so flow of air into and from these spaces is largely dependent on pressure differentials with surrounding areas. In the grinding/packaging room, mechanical exhaust from the area is facilitated by the fan ducted to the two grinding enclosures; however, no mechanical system for introducing outdoor air was present.

[d] No outdoor air was delivered to this space.

[e] ACH based on exhaust represents all transfer air from adjacent spaces.

[f] 77% of ACH based on exhaust represents transfer air from adjacent spaces.

[g] No mechanical air exchange with the outdoors, but leakage around garage doors accounted for some outdoor air into the facility.