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Improving IAQ at the Carnegie Mellon New House Dormitory

Field Research Supports Chamber Testing, Confirming that Avoiding
Desiccant Cross-contamination within Total Energy Wheels is Essential to
Optimizing Indoor Air Quality and Compliance with ASHRAE 62

Summary

A failed energy recovery wheel initially installed to precondition the outdoor air delivered to the New House Dormitory, a LEED certified facility located on the Carnegie Mellon campus, was retrofitted with fluted aluminum honeycomb transfer media coated with a 3 angstrom molecular sieve desiccant. Prior to installing the 3 angstrom media, the wheel was first retrofitted with transfer media identical to the 3 angstrom media in every way except coated with a silica gel desiccant. During normal operation, air samples were collected from the outdoor, supply and return air compartments surrounding the energy recovery wheel and analyzed using both a thermal desorption/gas chromatography/mass spectrometer (TD/GC/MS) and a real time, Innova photoaccoustical instrument.

Data was collected during two different seasons and compared to determine (1) if there was significant transfer of airborne contaminants from the exhaust to the supply airstream by the wheels and (2) to what degree any transfer compromised the indoor air quality of the dormitory space. In addition to the dormitory facility, a second CMU facility served by a plastic recovery wheel coated with a silica gel desiccant was also tested to provide a secondary point of comparison with the wheels investigated at the New House facility.

The results of the air quality testing confirmed that there was no detectible contaminant carry-over of exhaust air contaminants to the outdoor supply air stream by the 3 angstrom wheel, so the indoor air quality was not compromised while benefiting from the high percentage of energy recovery provided. In contrast, the silica gel wheel was found to transfer approximately 31% of the total volatile organic compounds (TVOC) from the exhaust to the supply air stream, resulting in a 54% increase in TVOC contaminants within the dormitory space, compared to operation with the 3 angstrom wheel. TVOC carry-over in excess of 50% was observed for the silica gel energy wheel operating at a second facility investigated on campus.

These results parallel previous research conducted by the Georgia Tech Research Institute which also evaluated the impact of energy wheel desiccant carry-over on ventilation effectiveness by comparing energy wheels using a 3 angstrom molecular sieve and silica gel desiccants. The research concluded that “due to the contaminant transfer associated with the silica gel desiccant, the outdoor air flow necessary to reach the same level of air quality as that provided by the 3Å wheel, had to be increased by approximately 66% and 80% respectively for isopropyl alcohol (IPA) and acetaldehyde”.

Background

A failed energy recovery wheel initially installed to precondition outdoor air to the New House Dormitory, the first LEED certified facility located on the Carnegie Mellon campus, provided an opportunity to investigate the impact of desiccant carry-over within total energy wheels on the resultant indoor air quality. The growing acceptance of LEED construction, rising energy prices and mandates by the building codes (i.e. ASHRAE 90.1) has significantly increased the use of total energy recovery wheels in building HVC systems. Since the primary driver for their integration is to provide “dilution ventilation” for improving IAQ within facilities, it is obvious that contaminant transfer from the exhaust to the supply could significantly compromise the main purpose for their use.

Design professionals unfamiliar with indoor environmental standards like those issued by EPA, NIOSH, WHO, European Standard, etc. would not know, for example that the recommended commercial building levels for total volatile organic compounds (TVOC) range between 500 to 1000 micrograms/cubic meter by those organizations. This relates to a level of contaminant concentration measured in the parts per billion range. Once understood, it is evident that significant contaminant transfer within an energy recovery wheel could make it difficult to reach the desired indoor air quality and the intent of ASHRAE Standard 62.

An investigation into current testing standards for total energy recovery devices has shown that the issue of desiccant wheel carry-over of typical indoor contaminants has not been addressed. Therefore, better understanding this issue is critically important to the industry, especially end users like Carnegie Mellon University.

The Robert L. Preger Intelligent Workplace (IW) located atop Margaret Morrison Carnegie Hall on the Carnegie Mellon Campus has employed a fluted aluminum honeycomb transfer media employing a 3 angstrom molecular sieve desiccant coating for approximately 10 years. First within a chilled-water based total energy recovery system (SEMCO EPCH-03) and now as part of an active desiccant vapor-compression hybrid preconditioning system (SEMCO Revolution 2250). The 3 angstrom energy wheel system was initially installed to replace a desiccant system that had introduced odors thereby compromising the air quality within the IW facility.

Since its installation, the 3 angstrom total energy wheel product has performed well and has helped to maintain the desired IAQ within the IW facility. Extensive field testing has been completed by researchers occupying the IW and these results, in part, served as the basis for one of the researcher’s PhD Thesis.

Energy Wheel System Installed at the CMU IW

The IW at Carnegie Mellon is operated as “a living laboratory” for the school of Architecture. As mentioned on the IW website, "the IW is also a wonderful place to undertake Ph.D. research projects, to test the impact of the built environment on thermal comfort, air quality, acoustic quality, lighting quality and the technologies or organizational changes possible in the workplace of the future." As a result, this energy recover/air quality research, completed on campus, and summarized by this document represents an excellent fit with the stated goals for the IW.

Previous Research

A 1999 Georgia Tech Research Institute (GTRI) investigation entitled "The Importance of the Desiccant in Total Energy Wheel Cross-contamination" was initiated to identify and quantify any differences between the desiccants used by commercially available desiccant wheels with regard to contaminant carry-over. Results from this investigation are presented graphically in the appendix section as Figure A1. These findings established clear performance differences between the various desiccant wheels. The 3A molecular sieve desiccant was shown to limit the transfer of the contaminants tested. The silica gel and 4A molecular sieves wheels could not, transferring up to 54% and 46% respectively of certain important indoor contaminants.

To quantify the negative impact on indoor air quality associated with the use of recovery wheels that allow significant contaminant transfer, a second GTRI research investigation was completed in 2004 using an environmental chamber to simulate ventilation within typical classroom.

The stated purpose of this research was to quantify (1) the impact on ventilation effectiveness by two desiccant wheels, identical in every way except that they used different desiccants (one using silica gel and the other using a 3Å molecular sieve) and (2) how much more outdoor air was needed to compensate for any desiccant contaminant carry-over observed in order to reach compliance with the intent of ASHRAE Standard 62. The final report is entitled "Total Recovery Desiccant Wheel Pollutant Contaminant Challenge: Ventilation Effectiveness Comparison".

This report concludes that "due to the contaminant transfer associated with the silica gel desiccant, the outdoor air flow necessary to reach the same level of air quality as that provided by the 3Å wheel, had to be increased by approximately 66% (352 cfm) and 80% (396 cfm) respectively for isopropyl alcohol (IPA) and acetaldehyde". These results are shown graphically as Figure A2 contained within the appendix section.

These results highlight the importance of selecting a total energy wheel that can avoid contaminant carry-over. Increasing the outdoor air to overcome contaminant transfer by the amount suggested by the GTRI research would negate any economic benefit associated with the total energy wheel. Clearly energy recovery without contaminant carry-over is required to preserve IAQ and to reduce energy costs and chiller/boiler first costs.

The investigation discussed in this document and completed on the CMU campus is a natural continuation of the 2004 GTRI chamber work, extending the research from the laboratory to actual building environments.

Discussion: Research Methodology - Installation

A silica gel energy recovery wheel installed within an air handling unit produced by a major HVAC manufacturer failed soon after occupancy of the LEED certified New House dormitory located on the Carnegie Mellon campus. Aside from reducing energy cost at the facility, the energy recovery wheel was implemented to protect the heating coil and supplement the humidification capacity of the system during the heating season. During the cooling season, an effective energy wheel allows for a significant reduction in the required cooling capacity. As a result, the wheel failure at the dormitory facility created serious operation problems for the University.

New House Dormitory at Carnegie Mellon

Rather than run the risk of a repeated failure with the original recovery wheel, manufactured from stacked plastic ribbons coated with silica gel, the University decided to retrofit it with a fluted, aluminum honeycomb media. As a committed supporter of “sustainable and green” construction, CMU saw the opportunity to use the site to better understand the differences between energy recovery wheel products. Sharing that desire, the manufacturer of the “replacement” recovery wheels agreed to supply two sets of transfer media, one coated with silica gel and a second, final set of transfer media coated with a 3 angstrom desiccant surface. The later being the same technology that has been used at the IW for many years.

Aluminum Wheel Media Sections

New media sections were made using the aluminum honeycomb. Since access would not allow the replacement of the entire recovery wheel housing, the sections were made to fit the existing media support system. These pre-engineered media sections enabled the installation to be easily completed within several hours.

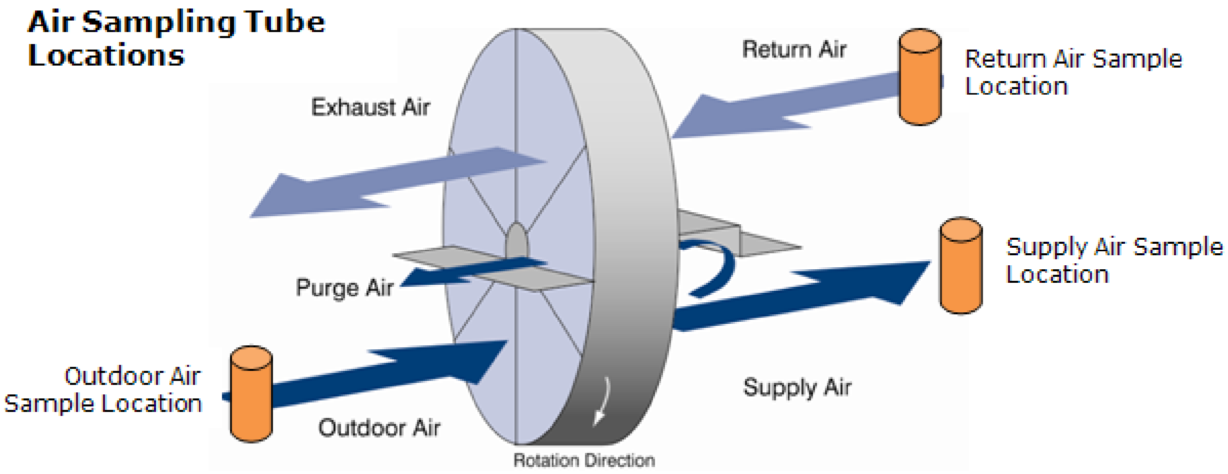
The new silica gel transfer media was installed first, and the system was allowed to operate as originally designed for approximately 16 hours prior to the collection of air samples within the various compartments of the air handling system. The silica gel desiccant selected was indicative of that used for years by several manufacturers of energy recovery wheels manufactured in the US and globally. The silica gel type used was the small pore product manufactured by Grace and marketed under the product designation Al-1 silica gel powder.

Following the air quality sample collection with the silica gel media operating, these new sections were removed and media sections, identical in every way with the exception of the 3 angstrom desiccant coating were installed in their place. These sections were put into operation for another 12 hours prior to another round of air sample collection.

In addition to installing the new media sections into the existing casing, a new drive belt and purge section was installed to minimize any contaminant carry-over, both long term and during the test program. In all cases, the wheel media was rotated by the original drive motor at a speed of approximately 35 revolutions per minute.

Discussion: Research Methodology – Sample Collection

Two sample collection visits and methodologies were used for this research. The first round of sample collection was completed during June of 2007. As described in the previous section, this involved testing both the silica gel and 3 angstrom molecular sieve wheels in the same air handling unit, during the same season and weather patterns, serving the same building with similar outdoor air quality, all within a 24 hour window. Samples were collected from the outdoor, return (occupied space) and well mixed supply (leaving the energy wheel) airstreams as shown below.



Round 1 sample collection

The air sample collection for this phase of testing was accomplished through the use of sampling tubes (3.5” x 0.25” o.d.) containing 250 mg of 60/80 mesh Tenax® TA adsorbent. Desorption, separation and detection were achieved by coupling a Markes automatic thermal desorption unit to a Thermo Trace Ultra gas chromatograph (GC) with a Restek RXI-5ms column for separation and a Thermo Trace DSQ mass spectrometer for detection.

Air Sample Collection Tube (MS/GC)

Quantitation of all compounds was completed by the Georgia Tech Research Institute based on the mass spectrometric response. Mass spectral interpretation was based on the best match to the NIST and WILEY mass spectral libraries, match to an authentic standard, or manual interpretation. Each peak concentration was totaled to compute the TVOC concentration for each sample.

Sampling tubes were placed in the outdoor, supply and return air streams surrounding the energy recovery wheel. The supply air sample tubes were consistently placed in the center of the wheel rotation to provide the best indication of average overall air quality leaving the recovery wheel. Following collection, the adsorption tubes were capped with Swagelok® caps with Teflon® ferrules and delivered to GTRI for analyses.

The sampling tubes were analyzed and corrected for VOCs detected in the field blanks. This data is shown within Table 1 and summarized graphically by Figure 1. The raw data is provided in the Appendix section 3.

Round 2 sample collection

The second round of sample collection was completed during January of 2008. In this case, only the 3 angstrom wheel was retested at the New House dormitory, in order to avoid the disruption associated with exchanging the wheel media two more times at this site during full occupancy and during the peak heating season.
A second round of testing at the dormitory with the 3A wheel was important to (1) provide confirmation of the data collected during the first round using a real time sampling source allowing CMU investigators to observe the data during collection and (2) to allow for data collection during the heating season and at peak occupancy.

New 3 Angstrom Media Installed

As suggested by CMU researchers, additional data of interest was obtained by completing similar air quality testing at a second building on campus served by an air handling system that included the same type of silica gel wheel that has failed at the New House facility. Doing so would provide an additional data point for a silica gel energy wheel while also offering some insight into the air quality impact at the second site.

During this second round of testing two methods of data collection were utilized. The adsorption tube method described in round 1 was used to provide a speciated listing of the top 12 indoor contaminants within the space and to provide a TVOC benchmark for comparison with the direct-read instrument.

An Innova Model 1312 photoaccoustical instrument was used for detection of volatile organic compounds (TVOCs). Instantaneous readout of the measured contaminant concentrations after an approximate 60-second measurement cycle allowed for easy observation by those present during testing. A calibration check of the Innova instrument was conducted prior to the tests.

Direct Read Innova Instrument Used

An integrated, calibrated pump pulls air samples directly from the respective airstreams through Teflon tubing. The data is analyzed and the concentration is reported on the display of the device as shown in the photo to the right.

The data provided by the Innova instrument was compared to the data provided by the mass spectrometer/gas chromatograph analysis completed by GTRI. Good agreement was found. These results are shown within Tables 2A and 2B and summarized graphically by Figure 2.

Results and Analyses:

Table 1 summarizes the results from the phase 1 testing which compared the two sets of retrofitted recovery wheel media, identical in every way, except for the desiccant material used. The data supports three very clear and important observations.

First, the data shows that the quality of the outdoor air passing through the wheel coated with a 3A molecular sieve was not compromised by desiccant transfer from the exhaust to the supply air stream. In contrast, approximately 31% of the contaminant concentration (total volatile organic compounds) differential between the exhaust and outdoor air streams was transferred into the supply air stream by the silica gel desiccant wheel ((53.6-38.2)/(87.1-38.2)).

Secondly, as a result of this transfer, the TVOC contaminant level within the supply air stream of the silica gel wheel was 51% higher than that delivered by the wheel coated with the 3 angstrom molecular sieve (53.6/35.4).

Thirdly, and perhaps most importantly, the contaminant concentration within the occupied space (i.e. the resultant indoor air quality) was 54% higher when the same building and occupancy was served with the silica gel recovery wheel media compared to the results when the 3A wheel media was in place (87.1/56.4).

Figure 1 summarizes these three findings graphically. These phase 1 findings were consistent with the chamber testing completed by the Georgia Tech Research Institute and as summarized by Figures 3 and 4 in the appendix section.

Since compliance with ASHRAE 62 assumes that the outdoor ventilation air is being delivered without compromise (as observed with the 3A molecular sieve energy wheel), attaining the desired indoor air quality level required by the standard would require the system employing the silica gel wheel to be operated with a significantly greater outdoor airflow volume.

Tables 2A and 2B summarize the results from the phase 2 testing. In this phase, through the use of the direct read Innova instrument, total volatile organic compounds (TVOC), carbon dioxide (CO2) and moisture transfer were measured and reported directly to researchers observing the data collection.

As shown in Table 2A, the 3A molecular sieve wheel once again limited TVOC contaminant carry-over as was observed as part of Phase 1 testing. In this case, testing was completed during the heating season and with a higher number of occupants (school in full session). It also limited carry-over of carbon dioxide.

This table also shows the results from the mass spectrometer/gas chromatograph analysis of the sample tube placed in the return air stream. This provided a speciated listing of the top 10 indoor contaminants, shown in Table 2A. Most importantly, the results of this analysis show a level of TVOCs that compares well with the level observed during Phase 1 testing. These results also agree well with the direct read data provided by the Innova (66.8 ppb vs. 60.8 ppb).

This Phase 2 data collection, completed during the month of January, also highlighted the beneficial latent recovery provided by the total energy wheel. The Innova instrument provided a direct readout of dew point (absolute humidity) coincident with the TVOC and CO2 readings. As shown, the 3A molecular sieve wheel media recovered 68% of the moisture differential between the outdoor and return air streams ((45.8-39.9)/(48.6-39.9)) while simultaneously avoiding the transfer of contaminants, as desired.

Table 1:

Date: June 2007

CMU New House Facility - IAQ and Total Energy Wheel Carryover Research (Phase 1)

Investigation of Two Wheel Media Types at Site - 3A Molecular Sieve and Silica Gel

Wheel 1: Silica Gel

Mass Spec/GC Data	Outdoor Air Stream	Supply Air Stream	Return Air Stream	Comments
TVOC from sample tubes mass spec/GC analysis (reported as benzene)	38.2 ppb	53.6 ppb	87.1 ppb	Identical to wheel 2 except silica gel desiccant is used in lieu of the molecular sieve

Wheel 2: 3A Molecular Sieve

Mass Spec/GC Data	Outdoor Air Stream	Supply Air Stream	Return Air Stream	Comments
TVOC from sample tubes mass spec/GC analysis (reported as benzene)	37.3 ppb	35.4 ppb	56.4 ppb	Identical to wheel 1 except 3A molecular sieve desiccant is used in lieu of silica gel

Summary of Findings

	Silica Gel	3A Molecular Sieve	Comments
TVOC Contaminant wheel Carry-over Measured % (1)	31%	none detectible	Identical to wheel 1 except 3A molecular sieve desiccant is used in lieu of silica gel
Supply air quality delivered to space	53.6 ppb	35.4 ppb	Silica gel wheel increases contaminants in the outdoor air by 37% while 3A wheel does not (2)
Resulting indoor air quality level	87.1 ppb	56.4 ppb	The 3A wheel resulted in a 36% better indoor environment using the same outdoor air volume (3,4)

Note 1: Carry-over percentage is calculated using the following contaminant levels: (Supply - Outdoor)/(Return - Outdoor)

Note 2: This increase is not desired since it compromises the indoor air quality and requires more outdoor air to reach the desired IAQ

Note 3: As expected, the higher supply air contaminant concentration associated with the silica gel wheel decreased this indoor air quality

Note 4: These results support the results of GTRI chamber testing (see GTRI report on desiccant carry-over and ventilation effectiveness)

Table 2A:

Date: January 2008

CMU New House Facility - IAQ and Total Energy Wheel Carryover Research (Phase 2)

Wheel Media Type at Site - 3A Molecular Sieve

Innova Instrument Data	Outdoor Air Stream	Supply Air Stream	Return Air Stream	Notes
Carbon Dioxide Data (PPM)	445	444	513 ppm	0% wheel carry-over
Dew Point Data (humidity)	39.9	45.8	48.6	68% latent recovery
Total Volatile Organic Compounds TVOC Data Average over 1 hour in Parts per Billion (PPB)	26.8	26 ppb	66.8 ppb	0% wheel carry-over

Mass Spec/GC Data	Outdoor Air Stream	Supply Air Stream	Return Air Stream	Notes
TVOC from sample tubes mass spec/GC analysis (reported as benzene)	Not analyzed	Not analyzed	60.8 ppb	Good agreement with Innova
Speciated top 10 indoor contaminants identified (concentration in microgram/M3)	decamethylcyclopentasiloxane		44.34	
	butoxyethanol		11.26	
	limonene		9.45	
	octamethylcyclotetrasiloxane		3.21	
	toluene		5.26	
	methyl ethyl ketone		3.25	
	acetone		3.06	
	hexamethylcyclotrisiloxane		1.23	
	pentadecane		3.19	
	decane		3.18	
	benzaldehyde		2.93	
	m- & p-xylene		2.69	
		Total	**194 microgram/M3**	**(60.8 PPB as benzene)**

Table 2B:

Date: January 2008

CMU Craig Street Facility - IAQ and Total Energy Wheel Carryover Research (Phase 2)

Wheel Media Type at Site - Silica Gel

Innova Instrument Data	**Outdoor Air Stream**	**Supply Air Stream**	**Return Air Stream**	Notes
Carbon Dioxide Data (PPM)	448	469	525 ppm	27% wheel carry-over
Dew Point Data (humidity)	39.7	37.5	38.5	No building humidification
Total Volatile Organic Compounds TVOC Data Average over 1 hour in Parts per Billion (PPB)	31 ppb	86.2 ppb	158 ppb	43% wheel carry-over

Mass Spec/GC Data	**Outdoor Air Stream**	**Supply Air Stream**	**Return Air Stream**	Notes
TVOC from sample tubes mass spec/GC analysis (reported as benzene)	Not analyzed	Not analyzed	130 ppb	Good agreement with Innova
Speciated top 10 indoor contaminants identified (concentration in microgram/M3)	decamethylcyclopentasiloxane		65.33	
	3-methylhexane		54.17	
	heptane		45.81	
	2-methylhexane		42.57	
	butyl acetate		24.77	
	butoxyethanol		21.72	
	2,3-dimethylpentane		12.34	
	3-ethylpentane		8.46	
	toluene		7.98	
	2-ethyl-1-hexanol		7.18	
	acetic acid		5.86	
	octamethylcyclotetrasiloxane		2.85	
		Total	**414 microgram/M3**	**(130 PPB as benzene)**

Table 2b summarizes similar testing completed at a second CMU facility served by an air handling system which incorporates a total energy wheel coated with a silica gel desiccant. As shown, carry-over of both TVOCs and carbon dioxide was observed. The measured contaminant transfer associated with TVOCs was found to be 43% for this system. Carbon dioxide transfer was also observed and was measure to be 27%.

Table 2b also shows the results from the mass spectrometer/gas chromatograph analysis of the sample tube placed in the return air stream, providing a speciated listing of the top 10 indoor contaminants and the total volatile organic compounds concentration. Once again the TVOCs measured agree reasonably well with the direct read data provided by the Innova instrument.

The data provided by Tables 1, 2A and 2B are summarized graphically by Figures 1 and 2. Figure 1 compares the Phase 1 air quality testing around the two recovery wheel transfer medias installed at the New House dormitory facility. Table 2 compares Phase 2 air quality data collected for the 3A molecular sieve desiccant wheel media installed at the New House facility, during the heating season, with that collected at the CMU Craig Street facility around a silica gel wheel serving that facility.

Figure 1 shows the ability of the 3A molecular sieve media to limit contaminant carry-over. Conversely the graphic shows the high degree of contaminant transfer rate (31%) associated with the silica gel wheel. The graphic presentation clearly shows the undesired impact on the resultant indoor air quality associated with contaminant transfer by the total energy wheel. As shown, the indoor contaminant levels (TVOC) were increased by 54% when the 3A molecular sieve media was replaced with the silica gel media, at the same ventilation rate and at a similar outdoor air quality.

Figure 2 shows graphical results that are consistent with Phase 1 testing – contaminant transfer was eliminated with the 3A molecular sieve wheel media, resulting in an improved indoor air quality while significant transfer by the silica gel wheel compromised the indoor air quality of the Craig Street facility.

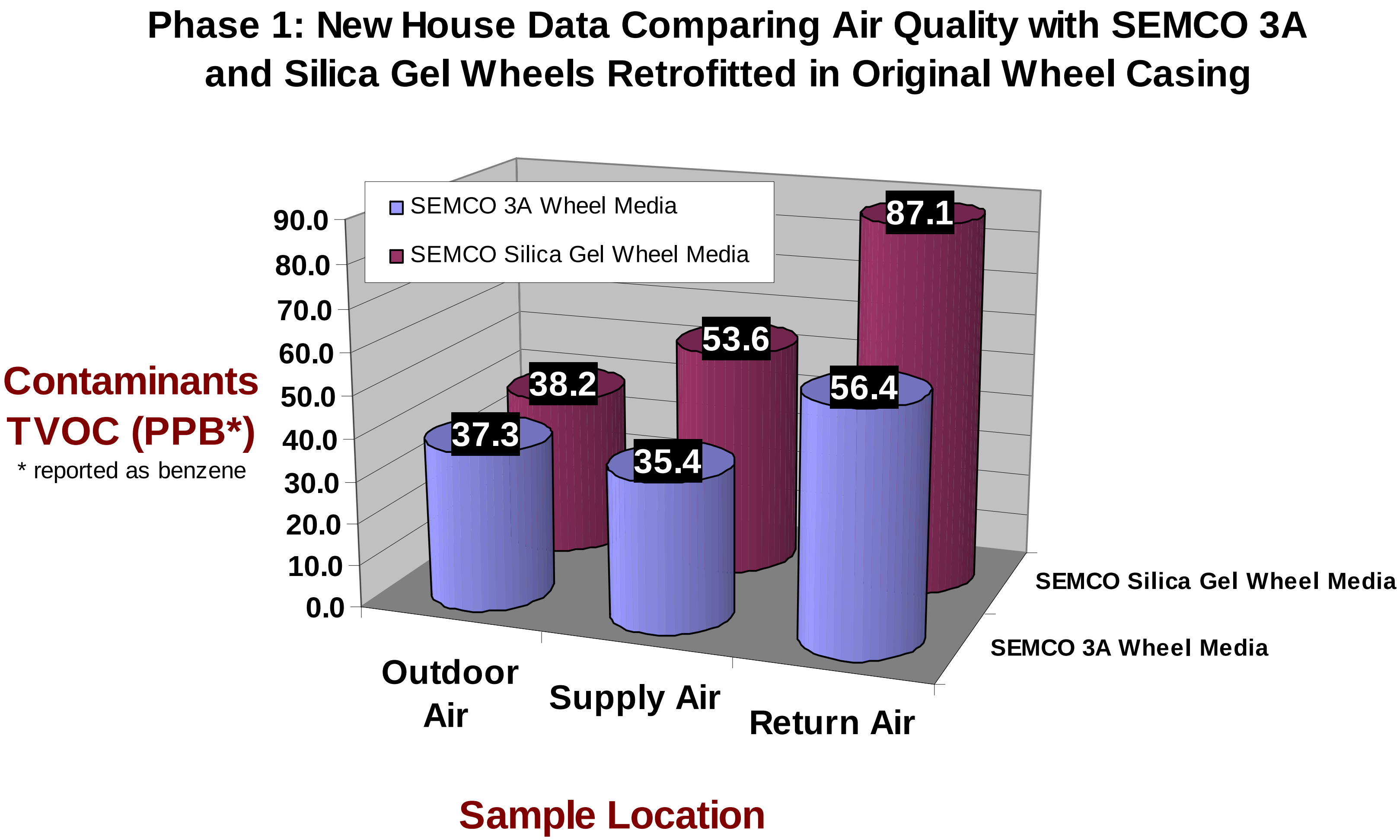


Figure 1: Graphical summary of mass spectrometer/gas chromatograph analysis of air samples collected around the two total energy recovery media types tested in Phase 1 at the New House dormitory. As shown, the 3A media limited contaminant carry-over and resulted in a 35% cleaner indoor environment for a given ventilation rate. The silica gel wheel compromised the resultant indoor air quality due to high percentage of contaminant transfer which significantly reduced the ventilation effectiveness.

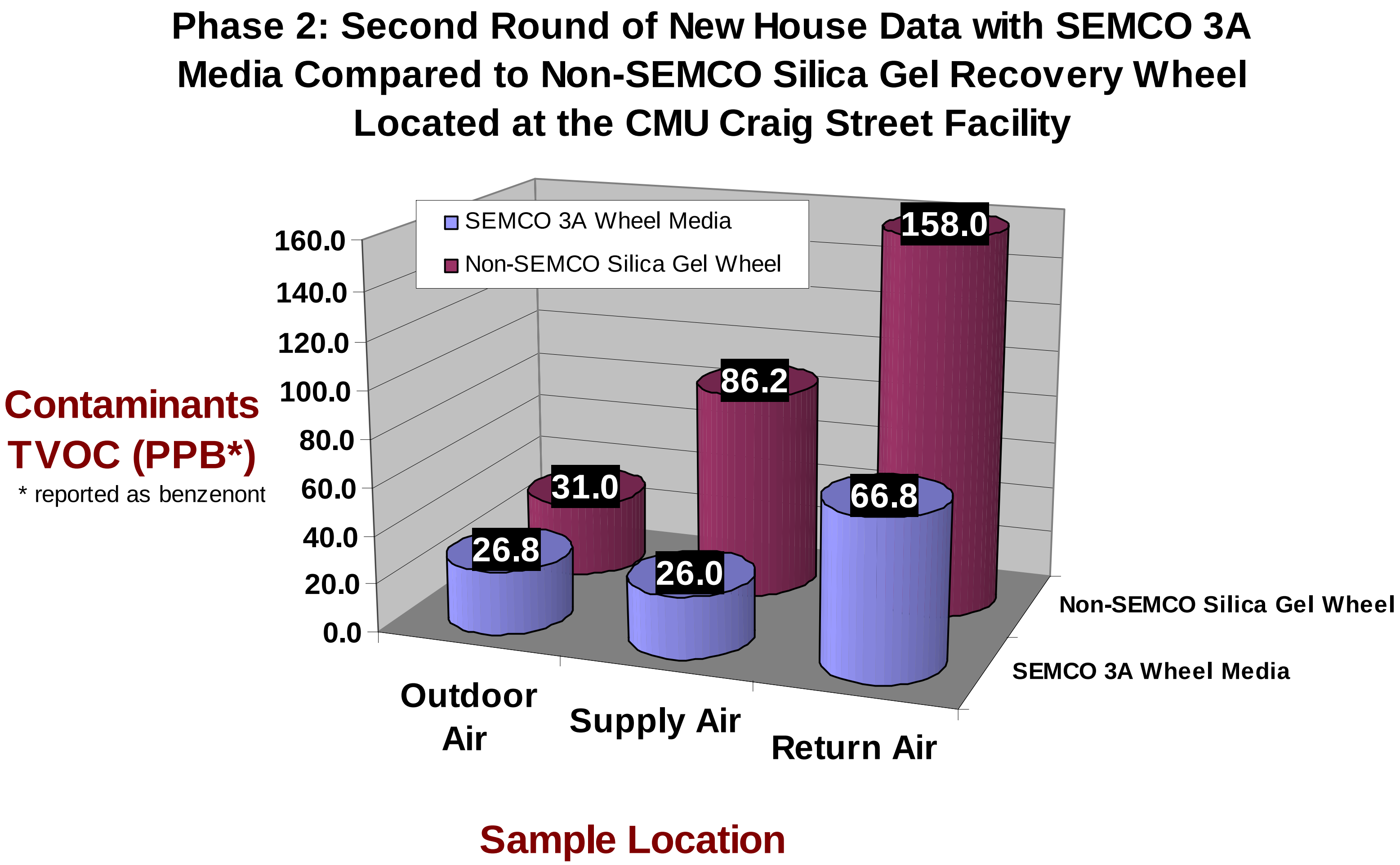


Figure 2: Graphical summary of the Phase 2 air samples collected around the 3A recovery wheel media at New House and a silica gel energy wheel installed at the CMU Craig Street facility. As shown, the results are consistent with Phase 1 testing – contaminant transfer was eliminated with the 3A wheel while significant transfer by the silica gel wheel compromised the resultant indoor air quality of the Craig Street facility.

Conclusions and Recommendations:

Several important conclusions can be made based on the results of this research project which investigated the impact of desiccant properties employed by commercially available total energy recovery wheels installed on the Carnegie Mellon Campus.

The desiccant properties associated with different total energy recovery wheels may significantly compromise the resultant ventilation effectiveness. The high degree of contaminant transfer observed (31- 43%) for the silica gel wheels investigated as part of this research project resulted indoor contaminant levels that were significantly higher than those observed when the contaminant carry-over was limited by the 3A molecular sieve wheel.

Indoor contaminant concentrations were found to be 54% higher when the New House Dormitory facility was served by the wheel transfer media incorporating the silica gel desiccant in lieu of the 3A molecular sieve wheel. Indoor air quality was compromised at the Craig Street facility due to the observed contaminant transfer associated with the wheel serving that facility.

To achieve the same indoor air quality as was provided by the 3A molecular sieve wheel (or a system operated without a total energy recovery device) significantly more outdoor air would have to be delivered by the silica gel wheel. These findings are consistent with data collected via chamber testing conducted by the Georgia Tech Research Institute and presented as Figure 4 within Appendix Section 2.

Data collected as part of this investigation at the New House dormitory as well as performance testing completed on the recovery wheel serving the Robert L. Preger Intelligent Workplace (IW) highlights the significant energy savings and environmental benefits associated with the use of total energy recovery wheel systems. Sensible and latent recovery efficiencies approaching 80% have been observed. For these reasons, standards like ASHRAE 90.1 and green building guidelines, like the LEED certification program used for the New House dormitory recommend or require the integration of total energy recovery wheels in many cases.

Since it is clear that compliance with the LEED program and ASHRAE Standard 62 assumes that the outdoor air quality being delivered by an energy recovery device is not compromised (significant exhaust air contaminants are not introduced into the outdoor air stream), performance testing that maps the degree of contaminant transfer by total energy recovery wheel products is critical design information and should be available from all manufacturers.

Without performance data to confirm that contaminant transfer is limited, the results of this research investigation has shown that a building owner may not achieve an acceptable indoor air quality despite paying for an energy recovery system that delivers the amount of outdoor air required by the building codes and ASHRAE Standard 62.

Appendix Section

Section 1: Previous Research – Laboratory Wheel Testing for Desiccant Cross-contamination of Common Indoor Contaminants

Research conducted by the Georgia Tech Research Institute (GTRI) in 1991 highlighted the ability of a total energy recovery wheel produced using a 3 angstrom molecular sieve desiccant coating to limit the transfer of exhaust air contaminants.

A subsequent GTRI research investigation entitled "The Importance of the Desiccant in Total Energy Wheel Cross-contamination" was initiated to identify and quantify any differences between the desiccants used by commercially available desiccant wheels with regard to contaminant carry-over. Results from this investigation are presented as Figure 3.

The GRTI research established clear performance differences between the desiccants used to produce commercially available total energy recovery wheels. The 3 angstrom molecular sieve desiccant wheel was shown to limit the transfer of all contaminants tested. The silica gel and 4A molecular sieve wheels did not, transferring up to 54% and 46% respectively of certain important indoor contaminants as shown below.

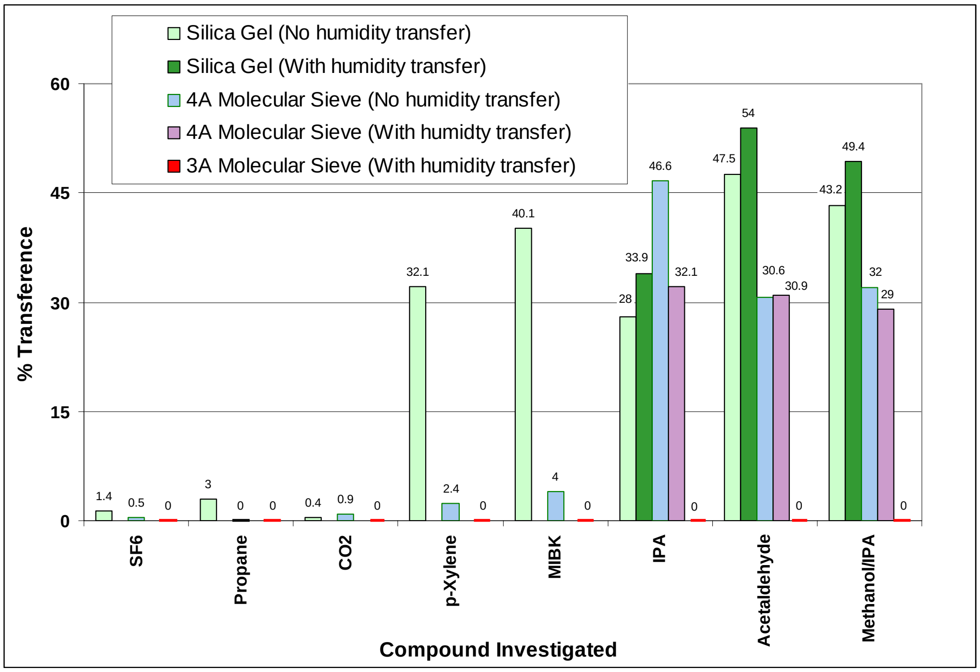


Figure 3: Results from the GTRI Report entitled "The Importance of the Desiccant in Total Energy Wheel Cross-contamination" comparing the resultant carry-over of three identical wheels using different desiccants.

As reported, the research completed at the CMU facilities and summarized by this report agrees well with the GTRI research results shown graphically in Figure 3.

Section 2: Previous Research – Chamber Testing to Investigate the Impact of Desiccant Used on Ventilation Effectiveness

In conjunction with a Department of Energy (DOE) sponsored research program investigating indoor air quality in school facilities the Georgia Tech Research Institute conducted testing to evaluate the impact that desiccant carry-over of airborne gaseous contaminants may have on ventilation effectiveness. The research concluded that depending upon the desiccant utilized, the transfer of common indoor air contaminants from the exhaust air stream into the supply air stream can be significant.

The GTRI report entitled "Total Recovery Desiccant Wheel Pollutant Contaminant Challenge: Ventilation Effectiveness Comparison" concluded that "due to the contaminant transfer associated with the silica gel desiccant, the outdoor air flow necessary to reach the same level of air quality as that provided by the 3Å wheel, had to be increased by approximately 66% (352 cfm) and 80% (396 cfm) respectively for isopropyl alcohol (IPA) and acetaldehyde."

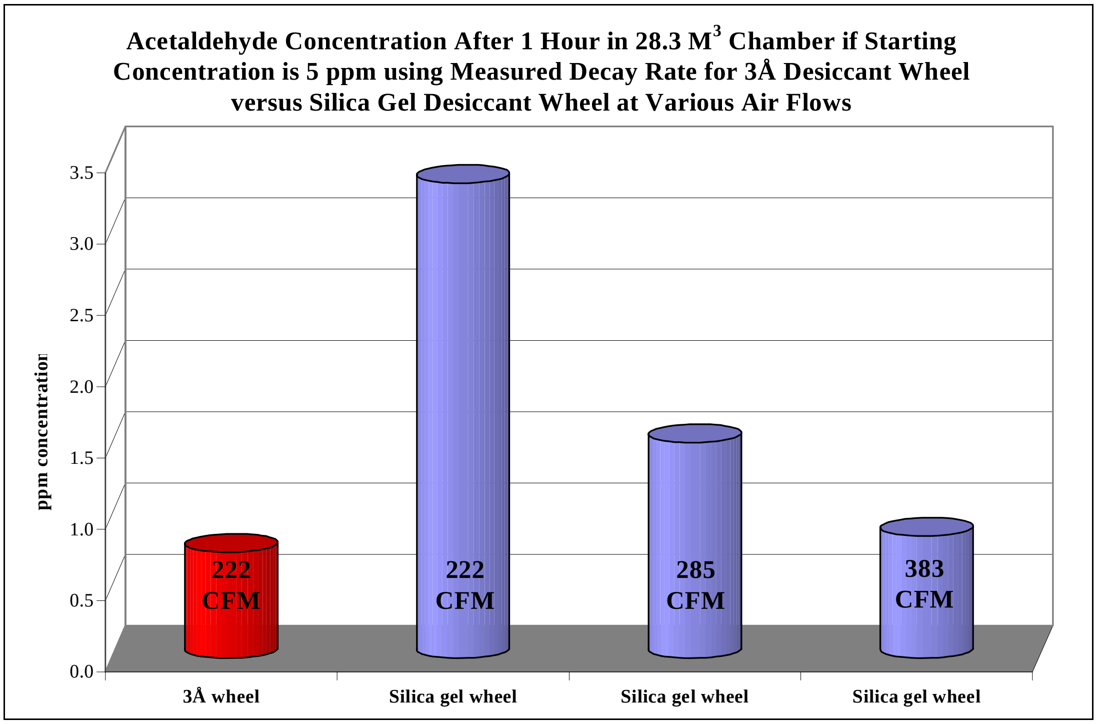


Figure 4: Acetaldehyde results from the GTRI final report. The data shows the significant impact that the desiccant used by a total energy recovery wheel can have on ventilation effectiveness and indoor air quality.

The GTRI research shows that the significant contaminant transfer associated with the silica gel wheel resulted in a significant compromise in the resultant indoor air quality. This chamber research was supported by the actual "field observations" made at the CMU facilities tested.

Section 3: Mass spectrometer/gas chromatograph results Phase 1

	Silica Gel Wheel, Supply Air	Silica Gel Wheel, Return Air	3Å Wheel, Supply Air	3Å Wheel, Return Air	Outside Air	Field Blank
Compound	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3	μg/m^3
2-formyloxy-1-phenylethanone	0.564	0.533	<0.001	<0.001	<0.001	<0.001
(1-butyloctyl)-benzene	0.475	1.27	<0.001	<0.001	<0.001	<0.001
(1-ethyldecyl)-benzene	0.133	0.456	<0.001	<0.001	<0.001	<0.001
(1-methyldecyl)-benzene	0.672	2.43	<0.001	<0.001	0.181	<0.001
(2-methoxyethyl)-benzene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
(m-terphenyl)-2'-ol	0.392	0.233	1.16	0.622	1.29	0.483
1,1,2-trichloro-1,2,2-trifluoroethane	0.003	<0.001	<0.001	<0.001	<0.001	<0.001
1,2,3-trimethylbenzene	4.26	5.57	1.4	2.83	6.28	0.049
1,2,4,5-tetramethylbenzene	<0.001	1.87	2.58	<0.001	0.553	<0.001
1,2-dibenzoylethylene	1.06	0.234	<0.001	<0.001	0.515	<0.001
1,2-diethylbenzene	0.833	10.16	<0.001	<0.001	2.17	<0.001
1,2-dimethylcyclopentane	<0.001	0.109	<0.001	<0.001	<0.001	<0.001
1,3,5-trifluorobenzene	<0.001	0.009	0.007	1.75	0.013	0.078
1,3,5-trimethylbenzene	0.852	1.16	0.349	<0.001	1.37	<0.001
1,3-butadien-1-ol	0.044	0.05	0.097	0.044	0.119	<0.001
1,3-diphenyl-2-propen-1-one	0.185	0.97	<0.001	<0.001	0.848	<0.001
1,3-dipropylene glycol	0.179	0.333	<0.001	<0.001	<0.001	<0.001
1,4-dioxane	0.11	0.182	<0.001	0.108	<0.001	<0.001
1,6-dioxcycylododecane-7,12-dione	2.46	1.14	2.22	1.17	<0.001	<0.001
10-methylanthracene-9-carboxaldeh	<0.001	<0.001	<0.001	<0.001	0.347	<0.001
1-butanol	4.27	0.141	0.087	0.411	0.112	0.045
1-butoxyl-2-propanol	3.27	11.4	2.82	6.88	0.799	<0.001
1-butoxypentane	0.189	0.199	<0.001	<0.001	<0.001	<0.001
1-dodecanol	0.697	5.05	<0.001	1.79	0.655	<0.001
1-ethyl-2-methylcyclohexane	0.037	0.088	0.19	0.239	0.135	<0.001
1-heptanol	<0.001	<0.001	0.586	1.03	<0.001	<0.001
1-hexadecanol	<0.001	1.83	<0.001	<0.001	0.3	<0.001
1-hydroxy-2-propanone	0.152	0.121	0.234	0.071	0.238	<0.001
1-methoxy-1-propene	<0.001	<0.001	<0.001	<0.001	0.073	<0.001
1-methylbutyl acetate	<0.001	0.447	<0.001	<0.001	<0.001	<0.001
1-methyl-1H-tetrazole	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1-methylnaphthalene	0.904	1.17	<0.001	1.21	1.86	<0.001
1-octanol	<0.001	2.6	<0.001	<0.001	<0.001	<0.001
1-propanol	0.642	0.033	0.013	0.053	0.032	0.02
1-propoxy-2-propanol	<0.001	1.87	0.445	1.36	<0.001	0.051
1-tridecanol	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1-undecanol	2.15	2.79	<0.001	<0.001	<0.001	<0.001
2-(2-butoxyethoxy)-ethanol	<0.001	<0.001	<0.001	11	<0.001	<0.001
2-(2-ethoxyethoxy)-ethanol	<0.001	<0.001	1.94	<0.001	<0.001	0.023
2-(2-methoxyethoxy)-ethanol	<0.001	2.23	1.53	0.8	<0.001	<0.001
2,2'-oxybis-1-propanol	<0.001	0.3	<0.001	<0.001	<0.001	<0.001
2,3,5-trimethyldecane	0.943	2.51	<0.001	<0.001	<0.001	<0.001
2,3-dihydro-4-methylfuan	<0.001	<0.001	0.023	<0.001	0.038	<0.001

2,3-dihydro-5-methylfuran	0.058	0.052	0.078	<0.001	0.081	<0.001
2,3-dihydrofuran	0.014	0.047	0.032	0.03	0.043	0.037
2,3-dimethylhexane	0.031	0.018	<0.001	<0.001	0.122	<0.001
2,5-dimethylhexane	<0.001	0.022	<0.001	<0.001	<0.001	<0.001
2,5-diphenyloxazole	<0.001	0.186	<0.001	<0.001	<0.001	<0.001
2,5-diphenyl-p-benzoquinone	<0.001	<0.001	<0.001	<0.001	<0.001	4.24
2,6-dimethyl-2-octanol	<0.001	0.188	<0.001	<0.001	<0.001	<0.001
2,6-dimethyl-7-octen-2-ol	<0.001	3.84	<0.001	<0.001	<0.001	<0.001
2,3-dimethylnaphthalene	0.116	<0.001	<0.001	<0.001	0.633	<0.001
2,6-dimethylnaphthalene	<0.001	0.786	<0.001	<0.001	<0.001	<0.001
2,4-hexadienal	0.026	<0.001	0.13	<0.001	0.089	<0.001
2,5-dimethylhexane	0.021	<0.001	0.024	<0.001	0.063	<0.001
2,5-diphenyloxazole	0.526	<0.001	<0.001	<0.001	0.87	<0.001
2,5-fuandione	<0.001	<0.001	0.249	<0.001	0.27	<0.001
2,5-hexanedione	<0.001	<0.001	<0.001	<0.001	0.223	<0.001
2,6-dimethylnaphthalene	0.219	<0.001	<0.001	<0.001	<0.001	<0.001
2,9-dimethylundecane	0.228	<0.001	<0.001	<0.001	<0.001	<0.001
2-butoxyethanol	6.28	25.37	7.04	16.1	1.99	0.034
2-cinnamoylbenzofuran	4.42	0.516	<0.001	2.49	0.757	<0.001
2-ethyl hexanoic acid	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
2-ethyl-1-hexanol	<0.001	<0.001	3.6	0.611	<0.001	<0.001
2-methyl-3-pentanol	<0.001	<0.001	<0.001	0.36	<0.001	<0.001
2-ethyl-2-phenyl-1,3-dioxane-4,6-di	0.692	1.45	<0.001	<0.001	<0.001	<0.001
2-hexene	0.021	<0.001	<0.001	<0.001	0.07	<0.001
2-hydroxyacetophenone benzoate	1.25	<0.001	2.33	<0.001	1.85	0.708
2-methoxynaphthalene	<0.001	0.462	<0.001	<0.001	<0.001	<0.001
2-methyl-1,3-pentadiene	0.018	0.024	<0.001	<0.001	0.022	<0.001
2-methyl-1H-pyrrole	<0.001	0.176	<0.001	<0.001	<0.001	<0.001
2-methyl-3-pentanol	<0.001	<0.001	0.489	<0.001	<0.001	0.009
2-methylbutane	0.109	0.151	0.012	0.054	0.065	0.004
2-methylfuran	0.039	0.406	0.938	<0.001	0.051	<0.001
2-methylheptadecane	0.865	2.33	<0.001	<0.001	0.284	<0.001
2-methylhexane	<0.001	<0.001	<0.001	<0.001	0.233	<0.001
2-methylnaphthalene	<0.001	<0.001	<0.001	<0.001	1.39	<0.001
2-methylpentane	0.146	0.156	0.11	0.118	0.269	0.024
2-octenal	0.936	5.13	<0.001	<0.001	<0.001	<0.001
2-pentanal	0.007	0.032	<0.001	<0.001	<0.001	<0.001
2-pentanone	<0.001	<0.001	0.21	0.196	<0.001	<0.001
2-pentene	0.017	0.1	0.012	<0.001	0.023	<0.001
2-phenoxyethanol	<0.001	3.32	2.25	2.52	<0.001	<0.001
2-phenoxyethyl isobutyrate	0.334	0.741	<0.001	<0.001	<0.001	<0.001
2-phenylacetophenone	1.72		2.01	1.25	1.96	0.175
2-piperidinecarboxylic acid	0.039	0.02	0.115	0.019	0.049	
2-propoxyethanol	<0.001	0.127	<0.001	<0.001	<0.001	<0.001
2-pyrrolidinone	2.7	<0.001	<0.001	<0.001	<0.001	<0.001
3,3,4,4-tetrafluorohexane	<0.001	0.002	0.441	0.162	0.38	0.423
3,3-dimethylhexanal	0.003	<0.001	<0.001	<0.001	<0.001	<0.001

3,3-dimethyloctane	0.186	0.219	<0.001	<0.001	0.784	<0.001
3,4-dimethyl-2-hexanone	1.19	1.11	1.3	3.17	0.917	<0.001
3,4-dimethylstyrene	1.12	<0.001	<0.001	<0.001	<0.001	<0.001
3,6-dimethylundecane	<0.001	<0.001	<0.001	2.87	<0.001	<0.001
3-ethyl-2,4-dimethylpentane	0.178	0.244	<0.001	<0.001	<0.001	<0.001
3-chlorbenzotrifluoride	<0.001	<0.001	0.13	<0.001	0.189	<0.001
3-ethyl-2-methylpentane	0.041	<0.001	0.019	<0.001	0.061	<0.001
3-methyl-2-heptanol	<0.001	0.27	<0.001	<0.001	<0.001	<0.001
3-methylfuran	0.234	0.209	0.123	<0.001	0.484	<0.001
3-methylheptadecane	0.653	0.866	<0.001	<0.001	0.181	<0.001
3-methylheptane	<0.001	<0.001	0.151	<0.001	0.352	<0.001
3-methylhexane	0.175	0.12	<0.001	<0.001	0.449	<0.001
3-methylpentane	0.095	<0.001	<0.001	<0.001	0.124	<0.001
4-(methylthio)benzyl alcohol	<0.001	<0.001	0.03	0.107	0.091	0.084
4-benzyloxybenzoic acid	<0.001	<0.001	<0.001	<0.001	0.223	<0.001
4-ethyl-1-hexene	<0.001	<0.001	<0.001	0.237	<0.001	<0.001
4-methoxy-1-butene	<0.001	<0.001	<0.001	<0.001	<0.001	0.183
4-hydroxy-4-methyl-2-pentanone	1.54	<0.001	0.07	<0.001	0.077	<0.001
4-methyl-4-penten-2-ol	0.023	<0.001	<0.001	<0.001	0.031	<0.001
4-ethyl-m-xylene	<0.001	0.118	<0.001	<0.001	<0.001	<0.001
4-methylcyclopentene	<0.001	<0.001	0.041	0.117	<0.001	0.044
4-methylheptane	0.06	0.211	0.078	0.773	0.057	<0.001
4-pipecoline	<0.001	0.367	<0.001	<0.001	<0.001	<0.001
4-piperidinol	0.465	<0.001	<0.001	<0.001	<0.001	<0.001
4-tert-butylcyclohexyl acetate	0.698	1.45	1.93	1.31	2.2	<0.001
6,6-dimethylundecane	0.17	<0.001	<0.001	<0.001	<0.001	<0.001
α,α-dihydroxyacetophenone	3.25	<0.001	<0.001	<0.001	<0.001	<0.001
acenaphthene	0.361	1.97	<0.001	<0.001	0.379	<0.001
acetic acid	<0.001	0.036	0.167		0.231	0.333
acetone	0.387	0.116	0.17	0.382	0.167	0.301
α-hexyl-cinnamaldehyde	0.609	1.42	<0.001	<0.001	<0.001	<0.001
α-oxobenzeneacetonitrile	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
benzaldehyde	14.2	9.61	14.5	7.06	23.5	0.369
benzamide	1.1	1.63	1.77	<0.001	1.97	0.118
benzene	<0.001	0.333	1.33	0.641	1.92	0.183
benzeneacetic acid	<0.001	<0.001	<0.001	<0.001	1.05	<0.001
benzeneethanol	2.87	1.38	<0.001	<0.001	0.508	<0.001
benzonitrile	<0.001	<0.001	0.603	<0.001	1.24	0.096
benzophenone	1.46	2.55	1.6	1.44	1.32	<0.001
benzothiazole	2.81	9.39	3.98	4.2	2.79	0.325
benzyl benzoate	0.418	0.607	<0.001	5.13	0.431	<0.001
benzyl ester acetic acid	1.83	2.35	<0.001	<0.001	<0.001	<0.001
benzyl nitrile	<0.001	<0.001	<0.001	<0.001	0.946	<0.001
biisopropenyl	0.03	<0.001	<0.001	<0.001	<0.001	<0.001
butyraldehyde	0.108	0.198	<0.001	<0.001	<0.001	<0.001
caprolactam	0.317	0.863	2.17	<0.001	<0.001	0.061
carvone	<0.001	0.376	<0.001	<0.001	<0.001	<0.001

cumene	1.8	0.328	<0.001	<0.001	<0.001	<0.001
cyclobutanone	<0.001	<0.001	<0.001	<0.001	0.01	<0.001
cyclobutylamine	0.002	0.286	0.22	0.173	0.215	0.125
cyclohexane	0.022	<0.001	<0.001	<0.001	<0.001	<0.001
cyclohexene-4-carboxaldehdye	0.227	0.112	0.17	<0.001	0.307	<0.001
cyclohexyl cyclohexanecarboxylate	1.29	0.193	<0.001	<0.001	<0.001	<0.001
cyclopentanol	0.212	0.238	0.143	0.106	0.399	<0.001
decanoic acid	<0.001	2.32	1.73	1.87	<0.001	0.107
dibenzofuran	<0.001	<0.001	<0.001	<0.001	0.328	<0.001
dibenzothiophene	0.318	<0.001	<0.001	<0.001	0.122	<0.001
dibenzoylmethane	2.19	0.435	3.46	<0.001	3.99	0.591
dibutyl phthalate	<0.001	1.6	<0.001	1.1	0.152	<0.001
diethylformamide	3.61	1.31	<0.001	<0.001	0.511	<0.001
diisobutyl phthalate	<0.001	0.703	<0.001	<0.001	<0.001	<0.001
diphenyl ether	0.479	0.662	<0.001	0.658	<0.001	<0.001
diphenylethanedione	0.878	<0.001	<0.001	<0.001	0.903	<0.001
diphenylmaleic anhydride	0.61	0.681	<0.001	<0.001	0.771	<0.001
diphenylpropanetrione	1.88	<0.001	3.31	<0.001	3.36	0.132
dipropyl adipicate	0.923	1.03	<0.001	<0.001	0.835	<0.001
dipropylene glycol	<0.001	0.559	<0.001	<0.001	<0.001	<0.001
dipropylene glycol monomethyl eth	<0.001	0.237	<0.001	<0.001	<0.001	<0.001
dodecamethylcyclohexasiloxane	2.16	6.77	2.79	5.42	1.52	0.311
dodecamethylpentasiloxane	<0.001	0.879	<0.001	<0.001	<0.001	<0.001
eicosane	0.587	0.698	<0.001	<0.001	0.344	<0.001
ethyl acetate	<0.001	<0.001	<0.001	0.17	<0.001	<0.001
ethyl isopropyl ketone	0.014	0.017	<0.001	<0.001	0.14	<0.001
ethylbenzene	1.8	3.29	0.918	2.43	2.34	<0.001
ethylhexyl benzoate	<0.001	2.79	<0.001	<0.001	<0.001	<0.001
fomic acid	0.086	0.581	2.48	0.332	2.24	0.042
furfural	0.172	0.494	0.198	0.429	0.192	0.017
heptadecane	1.7	3.91	1.7	2.03	0.929	<0.001
heptane	0.517	1.27	0.464	0.599	0.993	<0.001
hexadecane	1.72	4.74	1.39	2.16	0.865	<0.001
hexadecanoic acid	0.926	4.31	<0.001	<0.001	1.11	<0.001
hexamethylcyclotrisiloxane	0.59	<0.001	0.347	0.775	0.422	1.5
hexanal	0.697	1.49	0.937	2.79	0.865	0.061
hexane	0.135	0.478	0.506	1.43	0.994	<0.001
hexylcyclohexanecarboxylate	<0.001	<0.001	3.77	2.12	<0.001	<0.001
hexylene glycol	<0.001	<0.001	0.759	<0.001	<0.001	<0.001
indophenol	<0.001	<0.001	<0.001	<0.001	<0.001	6.22
isomenthol	2.28	7.98	<0.001	<0.001	<0.001	<0.001
isoprene	0.042	<0.001	<0.001	<0.001	<0.001	<0.001
isopropyl myristate	<0.001	4.08	<0.001	<0.001	<0.001	<0.001
lilial	0.148	<0.001	<0.001	<0.001	<0.001	<0.001
limonene	0.385	3.15	0.436	2.44	0.5	<0.001
m&p xylene	4.88	6.82	1.73	5.47	5.75	0.069
m-cymene	<0.001	0.557	<0.001	<0.001	<0.001	<0.001

menthol	<0.001	<0.001	<0.001	4.5	<0.001	<0.001
methyl acetate	<0.001	<0.001	<0.001	<0.001	<0.001	0.058
methyl benzoate	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
methyl ester butyric acid	0.022	0.021	<0.001	<0.001	<0.001	<0.001
methyl ester methacrylic acid	0.04	0.081	<0.001	<0.001	<0.001	<0.001
methyl ethyl ketone	0.152	0.372	0.613	0.249	0.845	0.169
methyl isobutyl ketone	0.096	0.532	0.064	0.125	0.249	0.152
methyl vinyl ketone	0.378	0.385	0.389	0.436	0.645	<0.001
methylbutyrolactone	<0.001	<0.001	0.169	1.11	0.28	<0.001
methylcyclohexane	0.043	0.028	0.113	0.089	0.153	0.017
methylcyclopentane	<0.001	<0.001	0.08	0.075	0.089	0.027
m-ethyltoluene	0.946	0.987	0.322	0.749	2.69	<0.001
mono-2-ethylhexyl adipate	3.08	2.47	<0.001	<0.001	<0.001	16.6
m-phenoxybenzyl alcohol	0.21	<0.001	<0.001	<0.001	<0.001	<0.001
N,N-diethylbenzamide	2.85	4.11	<0.001	<0.001	<0.001	<0.001
N,N-dimethylformamide	0.088	0.289	<0.001	<0.001	<0.001	<0.001
n-amyl methyl ketone	0.353	0.906	0.308	0.576	0.545	<0.001
naphthalene	9.94	19.56	12.6	<0.001	0.866	1.74
n-butyl ethyl ketone	0.108	0.459	0.168	0.321	0.117	<0.001
n-butyl formate	0.033	0.083	<0.001	<0.001	<0.001	<0.001
n-butyl methyl ketone	0.038	0.095	0.5	<0.001	0.113	<0.001
n-hexyl acetate	0.19	<0.001	<0.001	<0.001	<0.001	<0.001
N-methylbenzamide	0.12	<0.001	<0.001	<0.001	<0.001	<0.001
N-methylsuccinimide	30.8	3.74	<0.001	<0.001	<0.001	<0.001
nonadecane	0.893	0.904	<0.001	0.554	0.485	<0.001
nonane	2.04	5.75	1.64	3.27	2.02	0.057
nonanoic acid	2.29	10.69	5.4	10.5	2.59	<0.001
n-pentyl formate	0.004	0.053	<0.001	<0.001	<0.001	<0.001
n-propyl acetate	0.038	0.023	<0.001	<0.001	<0.001	<0.001
nortricylanol	<0.001	<0.001	<0.001	0.173	<0.001	<0.001
octadecanal	<0.001	<0.001	<0.001	<0.001	0.373	<0.001
octadecane	0.752	1.81	<0.001	1.93	0.4	<0.001
octamethylcyclotetrasiloxane	1.48	4.25	1.84	5.23	2	1.1
octanal	1.92	2.72	3.52	4.68	1.68	0.077
octane	1.03	5.13	1.1	2.39	1.31	<0.001
octylcyclohexane	0.566	0.697	<0.001	<0.001	<0.001	<0.001
o-ethyltoluene	0.182	0.135	<0.001	<0.001	0.175	<0.001
o-xylene	1.63	2.14	0.942	2.06	2.24	<0.001
p-benzoquinone	<0.001	<0.001	0.323	<0.001	<0.001	<0.001
p-dichlorobenzene	0.954	0.868	<0.001	0.883	1.98	<0.001
pentadecane	<0.001	<0.001	1.56	2.32	1.37	<0.001
pentadecanoic acid	<0.001	1.04	<0.001	<0.001	0.229	<0.001
pentanal	<0.001	<0.001	0.416	0.341	<0.001	0.04
pentane	0.106	0.164	2.69	<0.001	0.104	<0.001
pentyl ester salicylic acid	0.578	0.863	<0.001	<0.001	<0.001	<0.001
pentylcyclopropane	0.023	0.182	0.07	0.54	0.089	<0.001
phenacylthiacyanate	<0.001	<0.001	<0.001	1.2	<0.001	<0.001

phenanthrene	1.47	<0.001	1.27		1.05	<0.001
phenol	1.7	3.42	4.56	41.2	3.3	0.125
phenyl acetate	1.04	2.26	<0.001	<0.001	<0.001	<0.001
phenyl benzoate	<0.001	<0.001	<0.001	<0.001	0.634	<0.001
phenylethyne	0.51	0.751	0.814	0.581	1.18	0.039
phthalic anhydride	0.594	<0.001	1.81	<0.001	1.64	0.064
propanoic acid	<0.001	<0.001	0.025	<0.001	<0.001	<0.001
propylbenzene	0.801	0.295	0.257	0.45	0.842	<0.001
propylene glycol	<0.001	<0.001	0.504	0.411	<0.001	<0.001
pyrrolidine	0.102	0.118	<0.001	<0.001	0.293	<0.001
sec-amylethylether	2.11	<0.001	<0.001	<0.001	<0.001	<0.001
sec-butyl propyl ether	<0.001	0.374	<0.001	<0.001	<0.001	<0.001
styrene	0.026	0.169	0.175	0.321	0.383	0.053
tert-butyl phenyl ether	<0.001	<0.001	2.59	<0.001	3.16	<0.001
tetrachloroethylene	1.05	1.67	0.298	0.941	1.16	<0.001
tetradecamethylcycloheptasiloxane	0.176	0.432	<0.001	<0.001	<0.001	<0.001
tetradecane	1.84	3.82	1.33	2.34	0.602	<0.001
tetradecanoic acid	<0.001	3.07	<0.001	<0.001	<0.001	<0.001
tetrahydrofuran	0.201	0.067	<0.001	<0.001	<0.001	<0.001
texanol (1)	2.29	5.85	<0.001	2.16	<0.001	<0.001
texanol (2)	2.08	5.02	1.97	2.92	2.06	<0.001
toluene	2.84	3.79	1.17	3.05	5.23	0.031
trans-p-tert-butylcyclohexylacetate	0.319	<0.001	<0.001	<0.001	<0.001	<0.001
tridecane	3.21	2.74	1.58	2.97	2.39	<0.001
triethylamine	2.64	0.017	<0.001	<0.001	0.112	<0.001
trimethylsilanol	<0.001	<0.001	<0.001	<0.001	<0.001	0.035
unidentified (RT 35.78)	3.33	2.55	<0.001	<0.001	<0.001	<0.001
vinyl benzoate	0.38	<0.001	4.66	0.818	5.86	<0.001
Total	**209**	**316**	**151**	**218**	**157**	**38**
Total after field blank correction	**171**	**278**	**113**	**180**	**119**	