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Occupant perceptions and a health outcome in retail stores

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ABSTRACT

Indoor Environmental Quality (IEQ) in commercial buildings, such as retail stores, can affect employee satisfaction, productivity, and health. This study administered an IEQ survey to retail employees and found correlations between measured IEQ parameters and the survey responses. The survey included 611 employees in 14 retail stores located in Pennsylvania (climate zone 5A) and Texas (climate zone 2A). The survey questionnaire featured ratings of different aspects of IEQ, including thermal comfort, lighting and noise level, indoor smells, overall cleanness, and environmental quality. Simultaneously with the survey, on-site physical measurements were taken to collect data of relative humidity levels, air exchange rates, dry bulb temperatures, and contaminant concentrations. This data was analyzed using multinomial logit regression with independent variables being the measured IEQ parameters, employees' gender, and age. This study found that employee perception of stuffy smells is related to formaldehyde and PM_{10} concentrations. Furthermore, the survey also asked the employees to report an annual frequency of common colds as a health indicator. The regression analysis showed that the cold frequency statistically correlates with the measured air exchange rates, outdoor temperatures, and indoor $PM_{2.5}$ concentrations. Overall, the air exchange rate is the most influential parameter on the employee perception of the overall environmental quality and self-reported health outcome.

1. Introduction

A number of previous studies investigated Indoor Environmental Quality (IEQ) parameters and their impacts on occupant perceptions of the environment. A few studies demonstrated that poor IEQ deteriorates both human health and productivity [28,14,20,30]. However, most of the existing studies focused on office, campus, and residential buildings [10,17,7,29]. Studies involving big-box retail stores are limited [8,9,22]. It is necessary to evaluate IEQ in retail stores due to varied occupant exposure time including the short-term (customer) and long-term (employee) exposure to indoor environment [9]. The poor IEQ in retail stores may affect both customer comfort and employee productivity. An existing study found that indoor CO_2 concentrations that exceed 1000 ppm were related to occupant complaints of sick building symptoms (SBS), such as drowsiness as well as irritation of eye, nose, and respiratory tract [22]. Additionally, IEQ affects the emotions and purchase decisions of customers, as well as the thermal comfort and working efficiency of employees [5]. Therefore, the evaluation of IEQ in retail stores may benefit both customers and employees.

The present study combines on-site measurements and a survey study, aiming to quantitatively evaluate possible correlations between the overall IEQ and employee perceptions in retail stores. The survey study investigates the employee IEQ perceptions of multiple indoor environmental properties, and the on-site measurements of environmental parameters provide additional insights into survey responses based on statistical analyses.

2. In-store measurements of indoor environmental quality (IEQ)

This study focuses on data collection in retail stores, but its design draws on the experiences with the Building Assessment Survey and Evaluation (BASE) conducted for the office buildings [12,18]. The current study covers 14 retail stores from Texas and Pennsylvania in five categories defined as home improvement, general merchandise, grocery, furniture, electronics, and office supply. The site measurements of IEQ parameters were performed from May, 2011 to July, 2012. The measured parameters provided a

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physical description of indoor environment, and provided data for a statistical analysis of the survey responses. The indoor measurements included two parameter types: (1) parameters related to indoor thermal conditions including air exchange rate (AER), relative humidity (RH), and indoor dry bulb temperature; and (2) parameters related to indoor air quality including formaldehyde, particulate matter 2.5 μm ($PM_{2.5}$), particulate matter 10 μm (PM_{10}), and total volatile organic compound (TVOC). Overall, the study collected more than two dozen indoor parameters related to IEQ, thermal comfort, and contaminants in a week long time period [32,36].

The IEQ measurements used two sampling methods including (1) a fixed sampling with instruments in fixed positions, and (2) mobile sampling with portable instruments installed within baskets or shopping carts. The fixed sampling is suitable for large or heavy instruments to obtain continuous datasets, but can only represent the IEQ conditions at certain locations in retail store buildings. The mobile sampling represents the overall store conditions, but the measurements provide discrete datasets. Table 1 shows the measured indoor parameters with corresponding sampling methods. Thermal parameters of the indoor environment were measured in multiple fixed sampling locations to represent the condition of overall thermal environment. Indoor contaminants were measured by mobile sampling to represent the integrated distribution of contaminants inside the stores.

The detailed data collection processes included following parameters:

(1) CO_2 concentrations

Many previous investigations reported a relationship between indoor carbon dioxide (CO_2) concentrations and health perceived air quality. The indoor CO_2 concentration is also associated to ventilation rate [6,31]. During the measurements, a commercial monitor (Telaire 7000) collected the indoor CO_2 concentrations for ventilation rate estimations, and an assessment of air mixing in the stores. The monitors collected data at five locations in each retail store for four to five days, with the elevation of 1.1 m–2.0 m above the floor in each location. The overall average indoor CO_2 concentration in all retail stores varied from 381 ppm to 716 ppm, indicating a sufficient amount of outdoor air based on the CO_2 concentration criterion [3].

(2) Air temperatures and relative humidity

Air temperatures and RH may significantly impacts the perception of IEQ. A study demonstrated that the perceived air quality decreases with the increase in air temperature and humidity at a constant pollution level [13]. The Telaire monitors with HOBO data loggers collected the indoor RH at the same locations where CO_2 measurements took place. For retail store buildings in

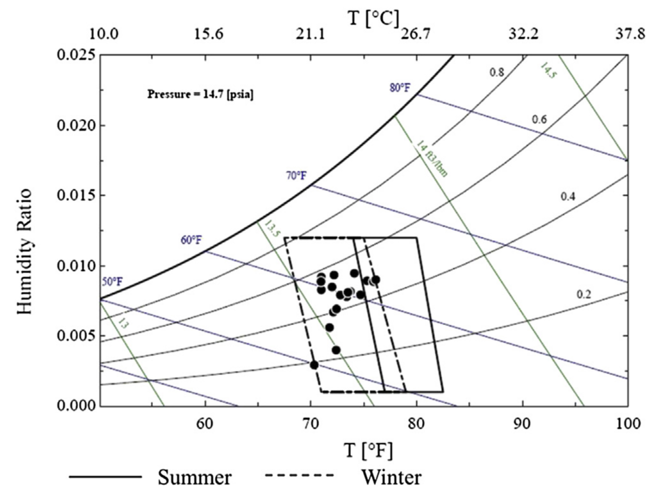

Fig. 1. Average indoor air humidity and temperatures in the psychrometric chart.

Pennsylvania, iButton sensors collected the data with three elevations above the floor, at 0.1 m, 1.0 m, and 1.7 m above the floor. Fig. 1 shows the average indoor air temperatures and relative humidity levels in retail store buildings within the psychrometric chart with all of the measured points being within the thermal comfort zone defined in the literature (ASHRAE, 2010). The highlighted region in Fig. 1 shows the range of operative temperatures and humidity ratios for 80% occupant acceptability. This region is based on a 10% dissatisfaction criteria for general thermal comfort.

(3) Volatile organic compound measurements

The complex mixtures of volatile organic compounds (VOCs) might be the primary source of mucosal irritation, a prominent symptom typically resulting in headaches, fatigue, and dizziness [16]. In the current study, sorbent tubes, summa canisters, and photoionization detectors (PID) measured VOC. The sorbent tubes were packed with 2, 4-dinitrophenylhydrazine (DNPH) monitored formaldehyde and acetaldehyde, based on the U.S. EPA Compendium Method TO-11A. The summa canisters were used to collect the air in the retail store buildings for VOC analyses. The PID (ppbRAE plus PGM-7240, RAE Systems, Inc.) monitored the TVOC concentration with both fixed and mobile sampling methods. The TVOC concentrations ranged from 38 ppb (100 $\mu g/m^3$) to 2955 ppb (6300 $\mu g/m^3$) with an average value of 799 and standard deviation of 826 ppb. The existing studies for different building types measured a wide range of TVOC concentrations with the averaged concentration values ranging from 126 $\mu g/m^3$ to 1393 $\mu g/m^3$ [34]. Overall, the studied retail environments have comparable TVOC concentrations to those measured in other studies.

Table 1
Measured IEQ parameters at the retail store buildings with fixed and mobile sampling approaches.

Method	Parameters	Type	Instruments
Fixed sampling	TVOC	Chemical compounds	ppbRAE Plus PGM-7240[a]
	Air temperature	Thermal comfort indicator	iButton, Telaire monitor
	CO_2 concentration	Thermal comfort indicator	Telaire monitor
	Relative humidity	Thermal comfort indicator	Telaire monitor
Mobile sampling	TVOC	Chemical compounds	ppbRAE Plus PGM-7240[a]
	Formaldehyde	Chemical compounds	Shinyei Formaldehyde multimode monitor, DNPH tubes
	$PM_{10,}$ $PM_{2.5}$	Particulate matter	TSI Side pak, TSI Dusttrak, met one Aerocet
	Air exchange rate	SF_6 decay method	SF_6 gas

[a] These instruments collected parameters by both fixed and mobile sampling methods.

(4) Formaldehyde concentrations

Formaldehyde concentrations were measured using tubes packed with 2, 4 dinitrophenylhydrazine (DNPH) and analyzed by accredited laboratories, following the U.S. EPA Compendium Method TO-11A. The indoor concentrations of formaldehyde were measured using DNPH tubes at all sites. Across all sites, formaldehyde concentrations ranged from 2.6 ± 0.3 ppb to 66.9 ± 8.3 ppb. The mean formaldehyde concentration was 18.1 ± 13.8 ppb, and the median formaldehyde concentration was 14.5 ppb. Office and furniture stores exhibited the highest formaldehyde concentrations compared to other store types [27]. The mean formaldehyde concentration in retail stores was slightly higher than that in the office buildings from the BASE study, which was 12 ppb [12]. Overall, formaldehyde concentrations in most stores were lower than the concentration that is odor detectable by human occupants [2,21].

(5) Particulate matter

The current study measured 5-min average indoors concentrations of PM_{10} and $PM_{2.5}$ with real-time photometers (TSI Sidepak, TSI Dusttrak, and Met One Aerocet) calibrated by the gravimetric technique. In this study, $PM_{2.5}$ and PM_{10} concentrations were 11 ± 10 μg/m^3, 20 ± 14 μg/m^3 [32]. Across all sites, there were no obvious associations of either PM [10] or $PM_{2.5}$ indoor concentrations with store type. In the BASE study, $PM_{2.5}$ indoor concentrations ranged from 1.3 to 24.8 μg/m^3 with a geometric mean of 7.2 μg/m^3, and PM_{10} indoor concentrations ranged from 3.0 to 35.4 μg/m^3 with a geometric mean of 11.4 μg/m^3. The indoor concentrations of $PM_{2.5}$ and PM_{10} were usually less than 16 μg/m^3. Compared to the BASE study, retail stores in the current study had higher concentrations of both $PM_{2.5}$ and PM_{10}.

(6) Outdoor air exchange rates

The current study measured air exchange rates using SF_6 as a tracer gas. After 1-h of mixing the released SF_6 in the stores, three field technicians simultaneously collected the room air samples at 12 to 18 sampling locations using 50 mL plastic syringes and injected the air samples into 1 L Tedlar sample bags. The sampling time was typically 4 hours to collect approximately 180 Tedlar sample bags at each store, with 4–6 min between repeated sampling. The calculation of outdoor air exchange rates used the measured SF_6 decay data, and the following single-zone mass balance equations for air volume of each store:

$$V\frac{dC}{dt} = -Q_{in}C_{in} + Q_{OA}C_{out} \tag{1}$$

where C_{in} (ppb) is the tracer concentration of indoor air, C_{out} (ppb) is the tracer concentration of outdoor air ($C_{out} = 0$), Q_{in} (m^3/h) is the air flow rate from indoor to outdoor, Q_{OA} (m^3/h) is the airflow rate from outdoor to indoor, V (m^3) is the indoor air volume, and t (h) is the time. Across all sites, air exchange rates ranged from 0.21 to 1.50 h^{-1}, with an average air exchange rate of 0.63 h^{-1} and standard deviation of 0.33 h^{-1}. Therefore, 83% of the measured ventilation rates met the minimum per floor area requirements in ASHRAE Standard 62.1 [19], while the average ACH is slightly lower than the measured ACH in a previous study of retail stores [4]. Furthermore, a previous study [34] found that the ventilation rates in retails stores are generally lower than those in bars/restaurants and healthcare facilities, and comparable to the ventilation rates in other environments such as fitness centers, residences, offices, and schools. Overall, the indoor environmental conditions of all the stores fell within the thermal comfort zone for occupants. Furthermore, compared to existing studies, these test stores had comparable VOCs concentrations, higher concentrations of both $PM_{2.5}$ and PM_{10}, and lower outdoor air exchange rates.

3. Survey study

The survey questions are either the same or similar to that of the Building Assessment Survey and Evaluation (BASE) study conducted by the Environmental Protection Agency [12]. The BASE study examined 100 office buildings during the 1990s to evaluate the occupant perceptions of office environments. The BASE study used a questionnaire with 32 questions classified by 4 categories: information about workplace, health, well-being, and characteristics of occupant work activities. The current study used five questions because longer versions of the questionnaire were not acceptable to store managers. Fig. 2 shows the layout of the questionnaire developed for this retail store study in collaboration with the Survey Research Center at the Pennsylvania State University. The questions include indoor environmental conditions, the overall cleanness, perceived indoor smells (stuffy air smell, chemical smell, and other unpleasant smell), overall indoor environmental quality, and annual frequency of common cold occurrences. In addition, the participating employees reported their gender and age to be included in the later analyses. The responses to each survey question had a three-level or five-level Likert scale, such as ratings from "too low" to "too high" for temperature, or "very poor" to "very good" for overall IEQ in the stores. The survey took 3–5 min to complete, and survey forms with unanswered questions were considered incomplete and were not used in the analyses.

The retail store employees participated in the survey voluntarily and anonymously. A total of 799 forms were collected, and 611 valid questionnaires were used for the survey analyses in this study. The survey completion rate of this retail store study was 76%, while the completion rate of BASE study was 86%. This completion rate is high, especially considering that the nature of retail employee work responsibilities is not associated with a desk and/or computer typical for the BASE study office employees. Table 2 shows the distribution of the sampled retail stores and employees. It is worth noting that the survey study design is not balanced because the number of employees varied from store to store. Specifically, 545 of the valid responses were from male respondents in this retail store study, while 34% were male respondents in the BASE study. Table 2 also shows that the survey was completed by the highest number of employees in general merchandise type of store, and the lowest number of employees in the furniture stores. It is important to notice that the examined sample of stores differed in employee density and store size, so the numbers of respondents reflect these differences. The table does not have cells with a count of less than 5, so the sparseness was not a problem.

The analysis of the survey results first included the histogram of all valid responses. Fig. 3 presents the histograms of responses to the first question, as well as the mean and standard deviation of each rating. Among the 611 samples, the mean ratings varied around 3, and less than 50% of employees were satisfied with the air movement, humidity, temperature, and noise level, while the majority of employees were satisfied with the lighting level. Most retail stores had low air movement ratings, while ratings for humidity, temperature, and noise level were skewed towards higher levels.

Fig. 4 shows the histograms for employee responses to indoor smell questions. More than half of involved employees did not sense any smell in the surveyed retail stores. Only 24% of respondents chose "weak" and 5% chose "heavy" ratings for the stuffy air smell. For the chemical smell, 19% chose "weak" and 2% chose "heavy". For other the unpleasant smell, 26% reported "weak" and 6% reported "heavy" smell.

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ASHRAE Indoor Environmental Quality Survey of Retail Buildings

Your gender: ☐Male ☐Female Your age___________

1. How do you rate each of the following environmental parameters as applied to this store/retail building?

Air movement ☐Too low☐Slightly low☐Just right☐Slightly high☐Too high
Humidity level ☐Too low☐Slightly low☐Just right☐Slightly high☐Too high
Air temperature ☐Too low☐Slightly low☐Just right☐Slightly high☐Too high
Lighting level ☐Too low☐Slightly low☐Just right☐Slightly high☐Too high
Noise level ☐Too low☐Slightly low☐Just right☐Slightly high☐Too high

2. How do you rate the level of overall cleanness in this store/retail building?

☐Very Good ☐Good☐Neutral ☐Poor ☐Very Poor

3. Do you smell anything and how strong this smell is if present in this store/retail building?

Stuffy smell ☐Heavy ☐Weak ☐None
Chemical smell ☐Heavy ☐Weak ☐None
Other unpleasant smell ☐Heavy ☐Weak ☐None
(food, tobacco, perfume, etc.)

4. How do you rate the overall indoor environmental quality, which is an overall indicator based on all surveyed parameters in the first three questions?

☐Very Good ☐Good ☐Neutral ☐Poor ☐Very Poor

5. In the last 12 months, how many common colds did you have?

☐None ☐1-2 times ☐3-4 times ☐More than 5 times

Fig. 2. Layout of the questionnaire filled by retail store employees.

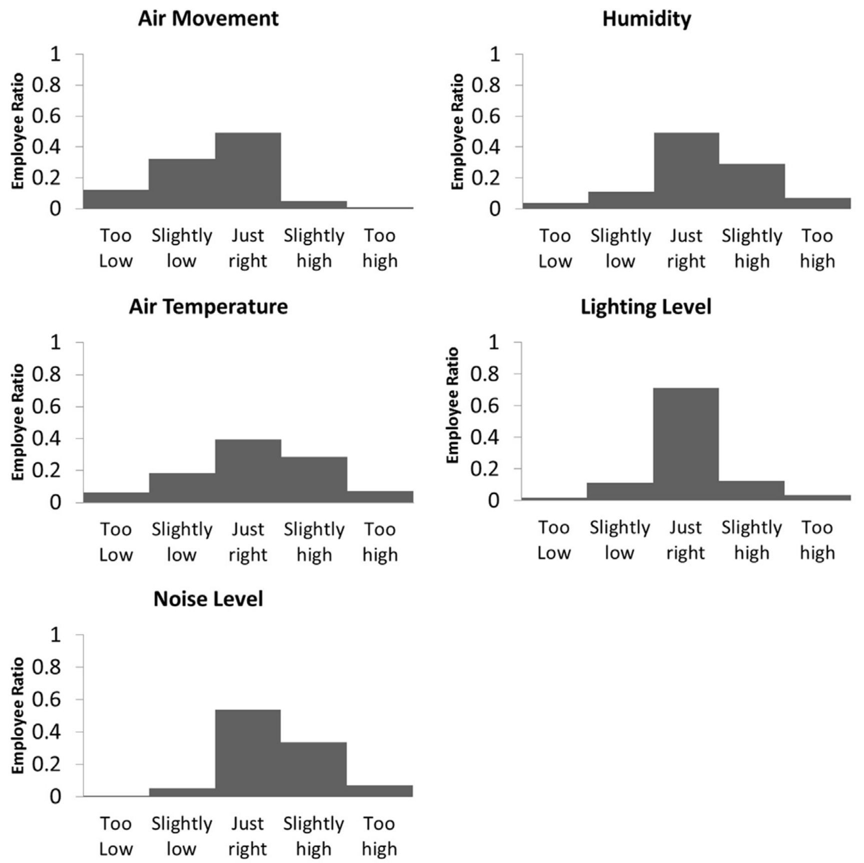
Table 2
Types of sampled stores and survey completion rate with gender distribution of surveyed employees.

	Electronics, office supply	Furniture	General merchandise	Grocery	Home improvement
Number of stores	3	2	2	4	3
Number of male respondents	49	16	129	62	73
Number of female respondents	30	17	120	53	62

Fig. 5 presents the histograms of the overall IEQ rating, overall cleanness, and the annual common cold frequency. Most employees considered that the overall IEQ and cleanness of the retail stores was good. Specifically, around 70% of employees chose "good" or "very good" ratings for the overall IEQ and cleanliness. Furthermore, less than 30% of employees did not have common colds in the past 12 months, and close to 60% of employees had only 1 or 2 occurrences. In the U.S., the annual rate of common colds is more than one billion, which on averaged would result in 3 or more common cold events per capita [1]. Therefore, the employees could be considered a healthy population, which is not a surprise considering their age distribution.

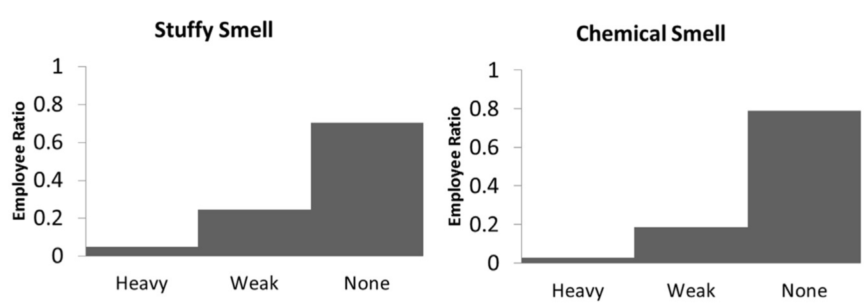
Even though the present study has a smaller sample and differs in the type of buildings, it is interesting to compare the survey findings of the current retail store buildings to office buildings in the BASE study. Table 3 compares survey responses obtained from the two studies. The percentages of respondents having negative sensations towards thermal comfort in the current study are much smaller than those in the BASE study. The percentage of respondents perceiving chemical smells in the current study is slightly lower, while the percentage of respondents perceiving other unpleasant smells is higher than that in the BASE study. Overall, according to their occupants, retail store environments had better thermal comfort, but worst perceived air smells than the office environments.

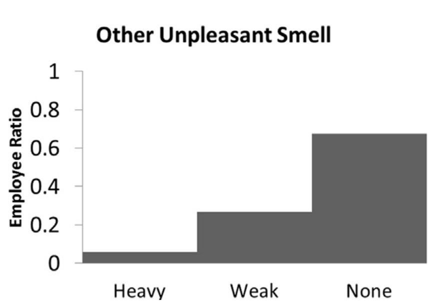
In summary, the survey results show that most retail stores had low air movement, while ratings for humidity, temperature, and noise levels were skewed towards higher levels. For the smell ratings, more than half of the involved employees did not sense any smell in the retail stores. Around 70% employee were satisfied with the overall IEQ rating and the overall cleanness. Furthermore, fewer than 30% of employees did not have common colds in the past 12 months. To further understand the survey responses, the current study performed statistical analyses to identify possible relationships between measured IEQ parameters and the survey responses.



	Air Movement	Humidity	Air Temperature	Lighting Level	Noise Level
Mean	2.486	3.262	3.147	3.039	3.427
Standard Deviation	0.7941	0.8872	0.9757	0.6441	0.7192

Fig. 3. Histogram of ratings for air movement, humidity, temperature, lighting and noise level in retail stores (1- Too low, 2- Slightly low, 3- Just right, 4- Slightly high, 5- Too high).





	Stuffy Smell	Chemical Smell	Other Unpleasant smell
Mean	2.661	2.759	2.615
Standard Deviation	0.5681	0.4886	0.5904

Fig. 4. Histogram of stuffy air smell, chemical smell and other unpleasant smell (1- Heavy, 2- Weak, 3- None).

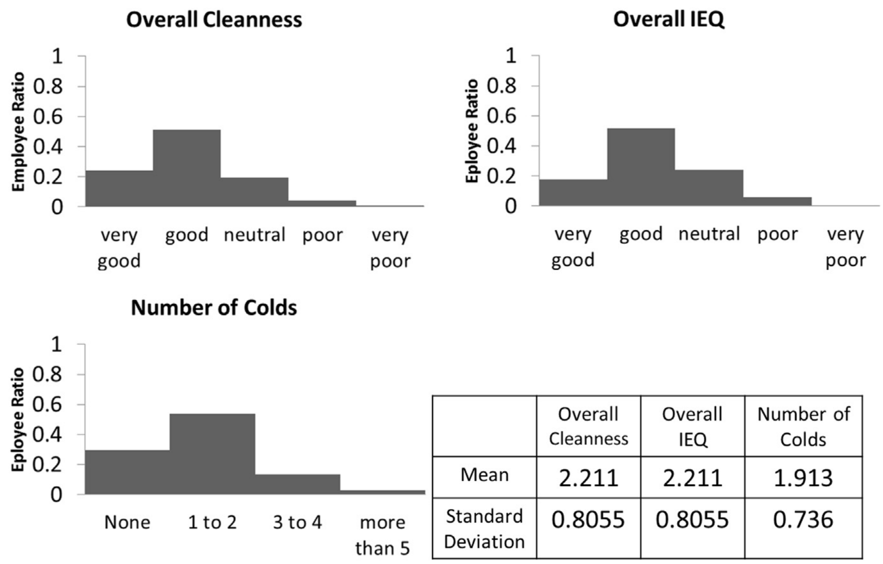


Fig. 5. Histograms of the overall cleanliness/IEQ of retail stores and the annual common cold frequency reported by employees (Overall cleanness and overall IEQ: 1- Very good, 2- Good, 3- Neutral, 4- Poor, 5- Very poor; Number of colds: 1- None, 2- 1 to 2, 3- 3 to 4, 4- More than 5).

Table 3
Comparison of survey responses to IEQ ratings.

Negative environmental perception	Current study %	BASE %
Too cold	5	26
Too hot	7	27
Too dry	4	25
Too humid	8	6
Too little air (low air movement)	13	31
Too much air movement	0.5	8
Chemical smells	3 (Heavy), 18 (Weak)	26
Other unpleasant smells	6 (Heavy), 27 (Weak)	16

4. Results and analysis

Statistical methodologies were used to further analyze the survey responses in two steps: (1) test the correlations between survey responses to different questions, to investigate if the IEQ ratings were independent of each other, and (2) develop logit regression models to explain survey responses with measured parameters.

4.1. Correlations of ratings with various IEQ parameters

For the overall indoor environmental rating, it is necessary to understand which rating of the individual IEQ parameter contributes most when employees rate the overall IEQ. Correlation tests utilizing the Spearman method were conducted for the overall IEQ rating and all the other ratings of individual IEQ parameters. Table 4 presents the test results, and shows that the overall IEQ rating statistically relates to all of the ratings of individual IEQ parameters (p-value<0.05). The overall IEQ rating has the statistically strongest correlation with the rating of overall cleanness ($r = 0.59$), air movement rating ($r = 0.41$), and stuffy air smell ($r = 0.35$). Therefore, based on our survey findings, IEQ is truly an integral occupant experience of multiple physical properties of the indoor environment.

4.2. Correlations of ratings and measured parameters

In order to understand employees' thermal sensation based on the measured parameters in retail stores, statistical methodology was used to analyze employees' responses to the questionnaires. The current study used the proportional odds cumulative logit model, which has a simpler format, compared to the generalized logit model, but it requires valid score test results for the assumption of proportional odds.

The cumulative logit model with proportional odds is common when analyzing multinomial ordinal responses, such as survey questions in the current study [23].

Table 5 shows all the potential independent variables to be chosen for the backward model selection algorithm using SAS (SAS Institute Inc.). The table lists the data range of continuous independent variables, and levels of categorical independent variables. The categorical variables, such as gender, were presented by “dummy” format: $X_i = 0$ for male, and $X_i = 1$ for female. Employees' demographic information, including gender and age, was considered to have the blocking effect, if these variables are included in the final logit models.

After analyzing the effects of potential terms in the model, only terms necessary for model assumptions or terms with a p-value smaller than 0.05 composed the logit models. The current study presents statistical models for 5 ratings of the survey, including overall IEQ, overall cleanness, air movement, stuffy air smell, and frequency of common cold event. Table 6 shows the results of score test, Deviance and Pearson statistics of goodness-of-fit test. The p-values in the table are all larger than 0.05, indicating that the developed cumulative logit models meet the assumption

Table 4
Results of correlation tests for overall IEQ rating and other ratings.

IEQ parameters	Air movement	Humidity	Air temperature	Lighting	Noise	Overall cleanness	Stuffy air smell	Chemical air smell	Other unpleasant smell
Correlation r	0.41	0.29	0.30	0.14	0.15	0.59	0.35	0.23	0.23
P-value	<<0.05	<<0.05	<<0.05	<<0.05	<<0.05	<<0.05	<<0.05	<<0.05	<<0.05

Table 5
List of the potential independent variables for model selection.

Type	Independent variables	Variable type, range/level
Employees' information	Age	Continuous, 18–73 yr
	Gender	Categorical, female & male
Measured indoor parameters	Air temperature	Continuous, 20–24 °C
	Relative humidity	Continuous, 17–57%
	Air exchange rate	Continuous, 0.2–1.5
Measured indoor contaminants	Formaldehyde	Continuous, 4.6–66.9 ppb
	PM10	Continuous, 3.1–59.5 $\mu g/m^3$
	PM2.5	Continuous, 2.2–46.3 $\mu g/m^3$
Measured outdoor parameters	Air temperature	Continuous, 3–35 °C
	Relative humidity	Continuous, 46–95%

Table 6
p-values for score tests and of goodness-of-fit tests.

Ratings	Score test	Goodness-of-fit test	
		Deviance	Pearson
Overall IEQ	0.06	1.00	0.87
Overall cleanness	0.15	1.00	0.40
Air movement	0.68	0.31	0.27
Stuffy air smell	0.20	1.00	0.34
Common cold frequency	0.13	1.00	0.50

requirements and fit the data.

The final logit model developed for each survey question include models for rating the overall IEQ, air movement, stuffy air smell, and common cold frequency.

(1) Model for rating the overall IEQ

Since the responses are highly skewed and fail to pass the score test, the response variables were collapsed into 3 categories: (1) Good (aggregate original 1st and 2nd category), (2) neutral (original 3rd category), and (3) Bad (aggregate original 4th and 5th category). With the collapsed data, the model for rating the overall IEQ is:

$$\log(P(Y \le k)/P(Y > k)) = \alpha_k + 9.31X_{AER} + 0.08X_{outdoor\ RH} - 0.13X_{AER}X_{outdoor\ RH} - 0.02X_{PM2.5} - 0.01X_{age} \quad (2)$$

where for k = 1, and 2, $\alpha_1 = -4.37$, and $\alpha_2 = -2.48$.

Table 7
Effects of measured parameters on the rating of overall IEQ.

Measured parameters	Positive effect	Negative effect
AER	46 < Outdoor RH < 71.6	71.6 < Outdoor RH < 90
Outdoor RH	0.2 < AER<0.6	0.6 < AER<1.5
$PM_{2.5}$	n/a	2.2 < $PM_{2.5}$<46.3

Table 7 summarizes the effects of the measured parameters on the overall IEQ rating. Employee perceptions of the overall IEQ ratings were statistically related to the outdoor relative humidity, air exchange rate, and indoor $PM_{2.5}$ concentration. The positive effect indicates that an increase in the corresponding parameter can result in higher odds of a positive rating towards the overall IEQ. For example, a 1 unit decrease of $PM_{2.5}$ ($\mu g/m^3$) leads to an increase in the estimated cumulative odds of the overall IEQ rating by 2% (calculated by exp(0.02)). Effects of AER and outdoor RH on the rating are combined because they are involved in a two-factor interaction term. It might be expected that the overall IEQ rating should have a higher correlation with indoor air temperature and relative humidity, but Fig. 1 shows that all of the indoor air temperatures and relative humidity levels were within thermal comfort zone. With these well-controlled HVAC systems, employee perceptions of the overall IEQ rating have a higher correlation with other environmental parameters.

(2) Model for rating the air movement

To meet the requirement of model assumption, the new collapsed response levels were: (1) just right (original 3rd category), (2) Slightly high or low (aggregate original 2nd and 4th category), and (3) not comfortable (aggregate original 1st and 5th category). The baseline response category was “just right” (i.e. Y = 2), and there were 2 logit equations in total:

$$\log\left(\frac{P(Y \le k)}{P(Y > k)}\right) = \alpha_k - 0.27X^{Gender}_{female} - 0.01X_{age} + 0.59X_{AER} - 0.20X_{temperature} \quad (3)$$

where for k = 1, and 2, $\alpha_1 = -14.93$, and $\alpha_2 = 16.90$.

From the coefficients in the model and Table 8, decreasing indoor temperature and increasing AER within the measured ranges can increase the odds of positive ratings towards the air movement. Specifically, decreasing indoor temperature by 1 °C and increasing AER by 0.1 can result in an increase in the estimated cumulative odds of ratings by 22% and 6%, separately. In addition, although the age does not have a discernible effect on the rating, the gender makes a 31% difference in the estimated cumulative odds of rating, when comparing the ratings of female and male employees. This result confirms that the perception of air movement depends not only on the thermal environment parameters, such as air velocity and temperature, but also on the personal factors, including overall thermal sensation and activity level [11]

Table 8
Effects of measured parameters on the air movement rating.

Parameters	Positive effect	Negative effect
Temperature	n/a	20 < Temperature<24
AER	0.2 < AER<1.5	n/a

(3) Model for rating the stuffy air smell

Another set of questions in the survey study were related to smells in the retail stores, including stuffy air smell, chemical smell, and other unpleasant smells. In particular, the rating of stuffy air smells has the statistically strongest correlation with the overall IEQ rating among the smell survey categories. The final logit model developed for stuffy air smell is:

$$\log\left(\frac{P(Y \le k)}{P(Y > k)}\right) = \alpha_k + 0.02X_{formaldehyde} + 2.80X_{AER} + 0.02X_{PM10} + 0.05X_{outdoor\ temo} - 0.15X_{AER}X_{outdoor\ temp} - 0.01X_{age} \quad (4)$$

where for k = 1, and 2, $\alpha_1 = -4.18$, and $\alpha_2 = -2.06$.

Table 9
Effects of measured parameters on the stuffy air smell rating.

Parameters	Positive effect	Negative effect
Formaldehyde	n/a	4.6 < Formaldehyde<66.9
PM10	n/a	3.1 < PM10 < 59.5
AER	19 < OA temp<35	3 < OA temp<19
Outdoor temperature	0.33 < AER<1.5	0.2 < AER<0.33

The outdoor temperature has a statistically significant correlation combined with AER on the ratings of stuffy air smell. Indoor contaminants also contribute to the rating. When the content of PM_{10} concentration decreases by 10 $\mu g/m^3$, the estimated cumulative odds of positive ratings increases by 22%, which shows that higher concentrations of $PM_{2.5}$ resulted in higher occupant sensitivity to stuffy smell. In addition, for 10 ppb decrease of formaldehyde concentration, the estimated cumulative odds also increased by 22%. Formaldehyde concentration in most stores with an average of 17 ppb, and only in one store where the concentration was over 50 ppb, were below the sensing ability of human occupants that is between 40 ppb and 400 ppb [21]. However, the results from this study shows that formaldehyde effects the ratings of stuffy air smell, and is correlated with the PM_{10} concentration. It is possible that when the particles are inhaled into human noses, larger sized particles (PM_{10}) can be deposited in the upper respiratory tract more easily than small sized particles ($PM_{2.5}$), so elevated PM_{10} concentrations can cause nasal irritation [33]. This propensity for nasal irritation could be the reason for higher occupant sensitivity to formaldehyde in the presence of higher PM_{10} concentrations (Table 9).

(4) Model for rating the common cold frequency

In this survey study, the employees were asked to provide the frequency of common colds for the past year with the following breakdown: (1) none, (2) 1 to 2 times, (3) 3 to 4 times, and (4) more than 5 times. The current study analyzed the frequency of common colds and their relationship to environmental parameters measured during the store visits, by assuming that the measured parameters represent the overall IEQ in the past year. The developed model is:

$$\log(P(Y \le k)/P(Y > k)) = \alpha_k + 0.51X_{AER} - 0.56X_{female}^{Gender} - 0.02X_{PM2.5} + 0.04X_{outdoor\ temperature} + 0.02X_{age} \quad (5)$$

where for k = 1, 2, and 3, $\alpha_1 = -2.35$, $\alpha_2 = 0.30$, and $\alpha_3 = 2.18$.

Table 10 shows the effects of the individual measured parameters. When the air exchange rate increases from 0.6 h^{-1} to 1.2 h^{-1}, the probability of reported common cold infection rate is decreased by 43% (for example: 3->2 or 1->0). When the air exchange rate increases, indoor air contaminants can be removed by the ventilation and filtration. This can help to reduce the concentration of bio-aerosol contaminants in the store environment associated with the common cold infection rate. An existing study analyzed sick leave records for employees in 40 buildings of a specific manufacturer, and found that the relative risk of short-term leaves increased by 35% when the air exchange rate was decreased [26]. The outdoor temperature, representing the weather conditions, is another important factor for the common cold infection rate. A decrease of the $PM_{2.5}$ concentration by 10 ppb can result in a 22% difference in the estimated cumulative odds. In addition, male and older employees reported higher frequency of common colds.

Typically, common colds can be caused by a number of different types of viruses. Also, different viruses in the cause of common cold vary dependent of several factors, such as age, season, and viral sampling and detection methods [15]. Therefore, not only the air exchange rates and $PM_{2.5}$ concentrations are correlated with the frequency of common colds, but also the age, gender, and outdoor temperature are correlated with the frequency of common colds. Interestingly, our results show that the gender has statistically significant correlation with both the rate of air movement defined by Equation (3), and the rate of common code frequency defined by Equation (5).

5. Discussion

The current study used regression analyses to find the correlation between survey responses and the physical parameters measured in the store environment. Employee perception of the overall environmental quality relates to the employee perceptions of air movement, overall cleanness, and stuffy smell. The survey findings show that IEQ is truly an integral occupant experience of multiple physical properties in the indoor environment. To identify which IEQ parameters may affect the employees' satisfaction towards the overall environmental quality, ratings of air movement, overall environmental quality, and stuffy smell were regressed with measured IEQ parameters. Fig. 6 shows the results from regression analyses as a relational chart among the overall satisfaction towards indoor environmental quality, other ratings in the survey (dark gray background), and measured parameters (light gray background). Among the survey ratings, Fig. 6 indicates that the ratings of air movement, cleanliness, and stuffy air smell have the statistically strongest correlations with the overall IEQ satisfaction based on results shown in Table 4. Furthermore, the overall IEQ satisfaction relates to measured parameters of indoor $PM_{2.5}$ concentrations, outdoor relative humidity, and air exchange rate. The ratings of the air movement relates to the measured parameters of indoor temperatures and air exchange rates. The rating of stuffy smell relates to measured air exchange rates, indoor $PM_{10,}$ and formaldehyde concentrations. Overall, the air exchange rate is the most influential measured parameter on the satisfaction with the overall environmental quality. Therefore, air exchange rates both

Table 10
Effects of measured parameters on the common cold annual frequency.

Parameters	Positive effect (less cold frequency)	Negative effect (more cold frequency)
AER	0.2 < AER<1.5	n/a
PM2.5	n/a	2.2 < PM2.5 < 46.3
Outdoor temperature	3 < OA temp<35	n/a

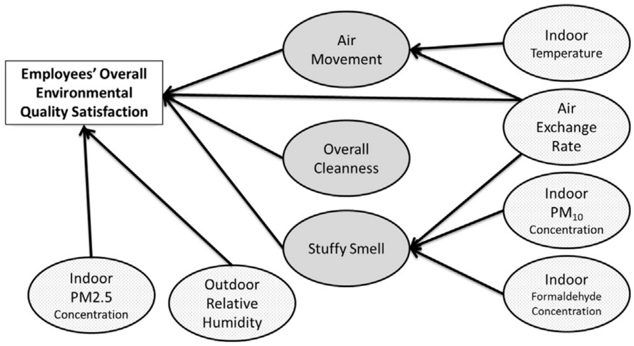


Fig. 6. Significant variables and their relationships based on the multinomial logistic models (please, note that the measured parameters represented with the light gray background and the survey outcomes are represented with the dark gray background).

directly affect the rating of overall environmental quality, and indirectly affect the ratings of the air movement and stuffy smell.

The IEQ can be affected by a wide range of variables, including location, time, occupancy and weather. Therefore, the current study has the following limitations:

1) The studied buildings are all retail stores as an important category of commercial buildings. The study results can provide insights for improving IEQ in retail stores, but the conclusions or at least the model equations may not be suitable for other types of commercial buildings.
2) All the regression models developed are based on variables in Table 5, so the correlations are valid when the variables are within identified measurement ranges. The correlations can be used to predict occupant ratings of specific IEQ aspects, but the input variables are limited by the ranges provided in Table 5.
3) All the questionnaires were collected during typical daytime business hours, but the questions did not address work schedules of the surveyed participants. Therefore, the results may not represent the IEQ during the nighttime or any other significantly different building operation mode, such the operation during the holidays.
4) The current study approach applies only to buildings with well-mixed air that results in approximately uniform distributions of indoor air parameters. The studied big-box retail spaces satisfied this condition based on SF_6, CO_2 and temperature measurements [32]. Nevertheless, smaller and more compartmentalized buildings, such as office buildings, may not have uniform parameter distributions.

The current study is focused on retail stores, but the results are comparable to the findings of other IEQ studies focused on other types of commercial buildings. For the rating of overall environmental quality, current study showed that the air exchange rates both directly and indirectly affect the ratings of the air movement, stuffy air smells as well as the common cold frequency. Similar findings exist for the office buildings, where a study analyzed the BASE data and showed that the most statistically significant parameters for the respiratory health outcomes included occupant perceptions of odors [35]. Interestingly, most of the previous studies based on IEQ data for commercial buildings, such as office buildings, did not provide equation-based models to link the environmental parameters to the occupant perceptions and health outcomes. Instead, these studies provided clear indications of different associations between the environmental parameters and occupant outcomes [12,25]. Nevertheless, these pioneering studies enabled the analyses conducted in the present study by developing both novel findings and data collection methods. Overall, it appears that the identified correlations should exist in commercial buildings in general, but their formulations need further improvements.

6. Conclusions

This study performed employee surveys and on-site measurements in 14 retail buildings. Each store data collection lasted for a week, with a total of 22 store visits over a two year time period to cover different seasons. The survey study aimed to understand employees' perceptions of the indoor environments, including temperature/humidity, air movement, perceived air quality, lighting, and noise levels. These survey responses were then analyzed based on correlation analysis and logit regression models. The correlation analysis shows that the employees' ratings of the overall IEQ have statistically significant relationship to all the other ratings of individual IEQ aspects listed in the survey. Specifically, the rating of overall IEQ has statistically strongest correlations with ratings of overall cleanness ($r = 0.59$), air movement ($r = 0.41$), and stuffy air smell ($r = 0.35$). This finding indicates that the overall IEQ is truly an integrated experience of the environment.

To further explain the survey responses with measured parameters, the cumulative logit regression method was performed to evaluate how measured parameters affected the ratings of overall IEQ, air movement, and stuffy air smell. Ratings of the overall IEQ are statistically related to measured parameters of outdoor relative humidity, air exchange rate, and indoor $PM_{2.5}$ concentrations. Interestingly, ratings of stuffy air smell are positively related to both indoor formaldehyde and PM_{10} concentration. Formaldehyde concentrations in most stores averaged 17 ppb, and were below the sensing ability of human occupants (i.e. 40 ppb–400 ppb), with the exception of one store that had a concentration over 50 ppb. However, surveyed employees experienced stuffy air smell in the presence of both elevated formaldehyde (still below the smell threshold) and concentrations of PM_{10} particles. During normal breathing, when the particles are inhaled with air into human noses, larger sized particles can cause nasal irritation and in this way sensitize the occupants, leading to a lower smell threshold.

The current study also analyzed the relationship between the annual frequency of common colds and the employee perception of overall indoor environmental quality. A statistically significant association existed between the rating of overall IEQ and the annual frequency of a common cold event, with a correlation coefficient of 0.3. This result shows that the overall IEQ could affect the employees' health. Specifically, the logit regression reveals statistically significant correlations between the frequency of common colds and measured IEQ parameters including air exchange rate, outdoor temperature, and $PM_{2.5}$ concentrations. Specifically, when the air exchange rates increased from 0.6 h^{-1} to 1.2 h^{-1}, the probability of common cold infection frequency decreased by 43% (for example by reducing the frequency from 3 to 2 colds/year).

In summary, the rating of the overall environmental quality is comprehensive, and based on employees' perception of multiple environmental parameters. Among the measured parameters in the current study, the air exchange rate is the most influential parameter towards employees' perceptions and a health outcome. Specifically, the air exchange rate has statistically significant correlations with the annual frequency of common colds, as well as the employee perceptions of overall IEQ, air movement and stuffy air smell.

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