Data inaccuracies in Texas state agency testing for ambient and indoor carbon dioxide concentrations 2005-2011

by

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Abstract

Purpose. The purpose of this paper is to explore indoor air quality assessment reports conducted by the Texas Department of State Health Services Environmental Hazards Group relative to building ventilation as measured by carbon dioxide (CO_2) concentrations. The TDSHS provides indoor air quality testing in public buildings as mandated in the Texas Government Code. *Method.* Ambient concentrations of CO_2 do not vary as widely as concentrations within indoor, occupied buildings. A range of 300-500 parts per million was developed as an acceptable concentration variance for ambient CO_2 levels. The ambient levels of CO_2 reported by TDSHS from each building were then compared to this range. If the ambient CO_2 levels from a specific site were within the range they were considered typical and normal. If the ambient CO_2 levels from a specific site were out of range they were considered suspect. *Results.* Of the 122 sites in the dataset, 31.15 percent were out of acceptable range and considered suspect. Of the data reported in one year of TDSHS site assessments, the percentage of suspect readings was 100 percent. This year was then followed by a year with 92 percent of all data out of range. *Conclusion.* Based on these results, TDSHS should examine all reported data from the Environmental Hazards Group for suspect CO_2 data and implement appropriate actions to determine why atypical and abnormal ambient CO_2 levels were reported. Employee training schedules and instrument calibration procedures should be assessed. Steps should be taken by TDSHS to address the issue of inaccurate interagency reports and to mitigate negative consequences. An agency oversight committee should be formed to assure the collection of reliable data or terminate the indoor air quality assessments offered to other agencies and seek third party companies to perform these assessments.

About the Author

Amber Conrad has a bachelor in Journalism and has worked as a news reporter and in state environmental regulation. She interned with Congressman John Carter, the Texas Commission on Environmental Quality, and the Texas Parks and Wildlife Department. Ms. Conrad graduated with a Masters in Public Administration with an enphasis on Urban and Environmental Planning in the fall of 2011. Ms. Conrad is a member of Pi Sigma Alpha, the national political science honor society, Gamma Theta Upsilon, the national geography honors society, the Society for Professional Journalists, and the American Society for Photogrammetry and Remote Sensing.

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Chapter 1

Introduction

Citizens in developed and developing countries spend over 90 percent of their time indoors. Due to poor air ventilation, indoor air can be up to 10 times more polluted than outdoor or amibent air.

Research in ambient and indoor air is used by private standards organizations and governmental entities to create guidelines and regulations for air quality. Data collected through application of these guidelines and regulations either validates or invalidates these standards. Therefore, it is important initial and subsequent data surrounding these guidelines and regulations be factual and accurate.

It is hypothesized that a descriptive statistical review of IAQ data will either validate or invalidate datasets used in IAQ research. To test this hypothesis, a sample dataset was collected from state indoor air quality assessment reports collected by the Texas Department of State Health Services (TDSHS). These assessments were conducted at the request of state public building managers through a Texas Government Code mandate. Testing by department environmental investigators is availiable in public buildings whose indoor air is questioned. The department does not charge for this service, and sends each building manager a copy of the buiding's assessment report.

This research analyzes data collected from 122 indoor air quality assessment reports conducted by the TDSHS from 2005-2011. It is imperative to examine this dataset because the agency does not perform internal analysis of these reports, nor has an open records request for this data ever been filled prior to this research.

Ambient CO_2 measurements were used to evaluate the overall validity of this dataset. The same instruments and department investigators were used to measure both indoor and ambient air at a given public building site, so if the ambient air is within a normal range then the recorded indoor levels should be equally accurate.

Ambient CO_2 levels do not vary as widely as indoor CO_2 levels, and so were analyzed using a range of 300-500 parts per million (ppm). This range was established through applying field testing instrument error ranges and the ambient range in CO_2 guidelines established by the American Society of Heating, Refrigeration and Air-Conditioning Engineers.

The analysis found 31.15 percent of ambient CO_2 levels in the dataset were not within an acceptable range for typical and normal CO_2 levels. In one year of the TDSHS study, 100 percent of the samples were out of the acceptable range for ambient CO_2 levels. In another year, 92 percent of the samples found ambient CO_2 levels out of the acceptable range for CO_2 levels. Based on the questionable ambient CO_2 data documented within the dataset, this TDSHS dataset is highly suspect and should not be used in evaluating overall building ventilation or as a mechansim to predict appropiate IAQ in the assessed buildings.

Suggestions for the current TDSHS testing program include expanding the program to include appropriate training of the individuals performing the assessments, documentation of instrument calibratition, and for the department to consider the elimination of the program and to seek and outside third party contractor to perform these services.

Chapter 2

Literature Review

Ambient Air

Outdoor, or ambient, air quality has been studied for decades privately and by public entities such as Congress, the American Lung Association, and the American Medical Association. Public awareness of ambient air quality has been raised through several high profile pollution events including the Donora, Pennsylvania smog in 1948 that killed 20 and sickened 30 percent of the town's residents, the 1952 winter during which polluted and stagnant air killed 4,000 Londoners in a single week, and the Boston soot fall of May 13, 1960. This soot fall left the city of Boston coated in a thick black blanket of soot that caused property damage and in some cases terminal illness in residents caught outdoors when the soot fell (National Association of Counties Research Foundation, 1965).

The United States introduced air quality standards after a series of congressional research reports studied the impacts of unregulated ambient air and its pollution on American health and property. The Air Pollution Control Act of 1955 funded air pollution research; then from that initial research the Clean Air Act of 1963 called for a governmental entity to regulate harmful airborne particulates and gaseous emissions. This regulation aided in the eventual establishment of the Environmental Protection Agency (EPA). The Air Quality Act of 1967 expanded research activities and authorized enforcement of interstate transport of pollutants (EPA 2010, H1).

The 1970 Clean Air Act and its amendments, commonly referred to as the CAA, codified many of the major regulatory initiatives still undertaken by the agency today, including the 1990 recognition and setting of standards for 189 toxic pollutants (EPA 2010, H1). The CAA also established an air emissions permitting program, expanded EPA's enforcement authority, and created programs to phase out the use of chemicals that deplete the ozone layer, and created a program for acid precipitation deposition control. The Act has been amended twice, once in 1977 pertaining to the National Ambient Air Quality Standards, and again in 1990 to "increase the authority and responsibility of the federal government," as well as increasing acid rain and ozone protection (EPA 2010, H1).

Authority for regulating these permitting programs has, in most cases, been delegated to individual states; however the EPA has sometimes chosen to take back the program from states. The EPA reclaimed the air permitting program from Texas in 2010, as the Texas program "did not meet several national requirements for protection of health and the environment" (EPA 2011, H2).

Indoor Air Quality

Indoor air quality (IAQ) refers to the air quality within buildings and structures, especially as it relates to the health and comfort of building occupants (EPA 2011, IAQ 1). The rise of air-conditioned buildings also led citizens in developed and developing countries to spend more time indoors. It is estimated that over 90 percent of an average developed world citizen's time is spent indoors (Alamari and Khamees 2009, 1306; EPA 1989). This increase in time spent indoors has exacerbated health issues caused by closed indoor air systems. A 1984 World Health Organization (WHO) Committee report found that, worldwide, upwards of 30 percent of buildings created or remodeled after the 1970s energy crisis were subject to excessive complaints from occupants relating to indoor air quality (WHO 2009, A). The EPA estimates that indoor air can be ten times more polluted than ambient air and classifies IAQ as one of the top five environmental risks to public health (EPA 2011, IAQ 1).

The scientific community has an established history of research in the area of IAQ. Several books relating to IAQ have been written by experts in the fields of environmental sciences (Godish 2001, 8), human health (Wadden 1983, v) political science and policy (Hays 2000, 1), engineering (Lindvall, Maroni, Seifert 1995, xi), and the social sciences (Copenhaver, Dudney and Walsh 1984, 1). The ALA, EPA, AMA, and the Consumer Product Safety Commission all cite the significant effects that indoor air pollutants have on respiratory and other forms of health (ALA 1994, 21).

It is generally accepted among environmental professionals that the modern rise of indoor air pollution concerns coincided with the 1973 oil embargo and subsequent energy crisis in the United States (Wadden 1983, 1; Hansen 2007, 18). Energy efficiency became a dominating factor in building construction. Edifices were sealed, indoor air re-circulated and synthetic building materials were emphasized to reduce energy costs. These methods, in lieu of traditional natural materials and methods, reduced costs associated with construction (Wadden 1983, 60). Additionally, these practices significantly reduced the energy used to maintain the living environment within structures, yet toxic particulates built up from synthetic building material off-gassing and poorly ventilated indoor areas remained trapped within buildings of all types.

The EPA lists many substances which are known to cause indoor air pollution. Carpeting, upholstery, manufactured wood products, copy machines, pesticides, cleaning agents, and tobacco smoke, are all examples of indoor materials that off gas chemicals called volatile organic compounds (VOCs) that can accumulate within an enclosed building space (EPA 2011, VOC 1). The EPA lists other sources such as unvented kerosene and gas space heaters, fireplaces, and wood and gas stoves. These sources release combustion products including carbon monoxide (CO) and nitrogen oxides (NOx) (EPA 2010, VOC 1). Chemical contaminants from outdoor sources may be introduced into an indoor environment through, for example, "poorly located air intake vents, windows, and other openings" and "from a nearby garage" (EPA 2010, IAQ 2). Biological contaminants such as molds, bacteria, viruses, dander, and excrement can collect in "ducts, humidifiers and drain pans, or where water has collected on ceiling tiles, carpeting, or insulation" (EPA 2010, IAQ 2). These sources may work in concert or separately to create physical ailments ranging from a "cough" and "allergic responses" to "Legionnaire's Disease and Pontiac Fever" (EPA 2010, IAQ 2).

In 1973, the same year of the energy crisis, the National Aeronautics and Space Administration (NASA) was monitoring the air circulating in its spacecraft. During the 1973 Skylab III mission, 107 VOCs were identified in the spacecraft from the off-gassing of synthetic materials used to design the vessel (NASA 2008). Research on VOC's led NASA to study "closed ecological life support systems" and the effects of chemical recirculation on human health within these systems through the next two decades (NASA 2008). In 1984 NASA published studies on a "bio-home" designed to test the effects of interior plants and other root-associated microbes on VOC levels in sealed test chambers (Wolverton 1996, 101).

The first EPA report to quantify indoor air pollution levels found over five hundred toxic substances and compounds in a ten public building survey (EPA 1988, 3). These buildings were chosen because indoor pollutant levels were considered normal by agency scientists. The study found chemical compounds known to cause health problems in ambient air were present in the indoor air at levels which exceeded ambient air at rates between sixty and one hundred times (EPA 1988, 3).

"Every home and every building are at least slightly polluted," said Eileen Claussen, a senior EPA air pollution expert at the time of the report (Milwaukee Journal 1988, 38). Pollution levels in new buildings are the highest, with levels remaining high for the first six months of the building's existence, and then slowly dissipating over the next ten years. The 1988 report was done on request from a Congressional mandate after several reports of indoor air quality concerns in the early 1980s (EPA 1988, 1).

The EPA followed the 1988 report with an additional report to Congress on IAQ in 1989 promising to "adopt and execute appropriate mitigation strategies" including "issuing regulations" (EPA 1989, 3). The 1989 report found higher levels of VOCs in public building air spaces; some sample locations with greater than nine hundred separate chemicals (EPA 1989, 6).

Though both the 1988 and 1989 reports along with other EPA IAQ reports were well-received by Congress, the documents did not produce a congressional call for indoor air quality regulation as similar documents over ambient air did in the 1960s. IAQ regulation opponents said not enough was known to devise a regulatory strategy for indoor pollution in the 1988 study. Despite over 20 years of research subsequent to the 1988 study, this still holds true for policy makers today.

Comprehensive lower-level limits for occupant comfort and long-term health for IAQ pollutants remain voluntary. However, various guidelines for IAQ exist from government and industry sources. These guidelines are set at different levels using various calculations. Each organization has faced pushback from interest groups even when setting suggested guidelines, often going through decades of effort to achieve printable guidelines.

The EPA does have comprehensive awareness materials available online compiled in a web site dedicated to IAQ issues with dedicated pages for major areas such as asthma, mold, and radon (EPA 2011, IAQ 1). The site links to information on indoor air quality in homes, large buildings, schools, and various programs offered by the agency such as the Indoor airPLUS Program, IAQ Tribal Partners Program (EPA 2011, IAQ 1).

Recently the EPA awarded $2.4 million in grants to "help encourage the public to take action to minimize their risk and mitigate indoor air quality problems" (Kika 2010, 1). The seventeen cooperative agreements that make up the grants were awarded to nonprofit organizations and one university. These entities are expected to "educate Americans on how to reduce the environmental health risks of indoor contaminants through demonstrations, education projects, trainings, and outreach efforts" (Kika 2010, 1).

Ceiling limits established for IAQ

While the EPA was struggling to gain Congressional support for IAQ regulation, the Occupational Safety and Health Administration (OSHA) along with its companion research agency the National Institute of Occupational Safety and Health (NIOSH) successfully regulated IAQ ceiling limits designed for industrial building occupant safety.

OSHA and NIOSH were created through the Occupational Safety and Health Act of 1970 (OSHA 1996). Prior to this act, American workers were not covered by comprehensive regulations for workplace hazards. At the time of this legislation, over 14,000 worker deaths were caused annually by job-related accidents, time lost on the job for work-related disability was 10 times that of time lost due to strike, and an estimated 300,000 new cases of occupational disease were reported annually (OSHA T 2011). These figures greatly impacted not only the health of the average American citizen, but affected domestic commerce across the nation. Congress passed the Act to not only "assure so far as possible every working man and women in the Nation safe and healthful working conditions," but also to "preserve our human resources" (OSHA 1996, 1).

OSHA was placed within the Department of Labor. The administration is responsible for regulation of the act, developing and enforcing standards for workplace health and safety. NIOSH was placed within the Centers for Disease Control and Prevention (CDC) in the Department of Health and Human Services. The institute creates research and provides educational resources and training in the field of occupational health and safety (CDC 2011).

In 1974 OSHA regulated the first 14 identified indoor air contaminants in response to "the growing recognition that chronic health effects were an increasing and little-examined aspect of workplace exposures" (OSHA T 2011). In 1976 the agency created additional emissions standards for steel production workplaces, furthering the list of regulated workplace pollutants. Lead was regulated in 1978, and in 1983 the Hazard Communication Standard (HCS) was issued. The HCS gave employees the right to know the chemicals to which they are exposed on the job and employers were required to create worker safety training programs around hazardous chemicals (OSHA T 2011). The agency issued several more instance-based IAQ standards for workers, and then in 1989 OSHA updated its existing Air Contaminants Standard, chapter 29 in the Code of Federal Regulations standard 1910.1000. Many of the existing Permissible Exposure Levels (PELs) were amended to more conservative and protective levels and the agency set new PELs for 164 substances. These new limits were immediately contested in the U.S. Court of Appeals, which invalidated the changes; however a stay in the mandate for legal action consideration allowed OSHA to continue enforcement of the 1989 PELs. In 1993 the agency published minor corrections and was able to codify these PELs (OSHA 1993).

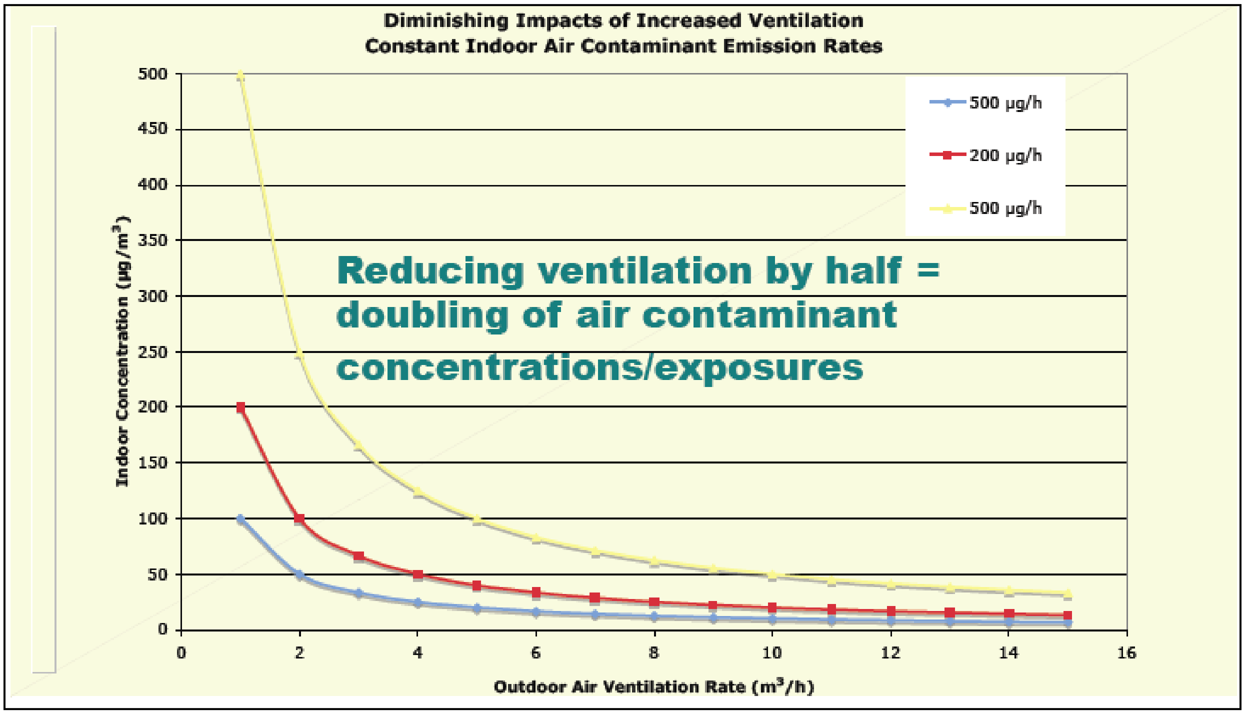
Where these enforceable ceiling limits regulate IAQ, they are designed to do so in an industrial setting, and are therefore only loosely applicable to the modern office or dwelling environment found in developed and developing countries.

IAQ studied through Carbon Dioxide

In IAQ research, carbon dioxide (CO_2) levels are traditionally associated with the functionality of a building's heating, ventilation, and air conditioning (HVAC) systems. Poor ventilation allows CO_2 and other indoor air contaminants to accumulate in occupied spaces. This link between HVAC system ventilation and negative IAQ symptoms makes CO_2 a crucial short-term indicator of potentially harmful conditions. Pollutants which have accumulated as result of poor ventilation may adversely affect occupant health in the medium or long-term. To counter these medium and long term health effects, a short term indicator of indoor air comfort and health is essential for due diligence in managing occupant safety.

OSHA states that for the "prevention and control of IAQ problems" building managers should specifically monitor CO_2 levels because "the carbon dioxide levels can be used as a rough indicator of the effectiveness of ventilation and excessive population density" (OSHA IAQ 2011, 7). ASHRAE data also supports CO_2 levels as a reliable estimate of HVAC efficiency and therefore a useful indicator of human comfort in occupied buildings (ASHRAE 62.1-2010). Figure 2.1 reveals that the reduction of air circulation within a building directly affects airborne contaminant levels.

Figure 2.1



Data from the Indoor Environmental Engineering 'Weatherization Plus Health presentation in Oakland, CA Sept. 27, 2011

CO_2 is one of the most abundant naturally-occurring gasses on Earth. It is colorless, odorless, non-flammable, and is most notable as a part of the carbon cycle. Globally, concentrations of carbon dioxide vary depending on plant growth and the availability of carbon sinks such as forests or oceans. These items absorb CO_2 from the atmosphere, driving levels lower during spring and summer months. Conversely CO_2 is released by the burning of fossil fuels, respiration, and commercial farming practices among others. The current average ambient CO_2 concentration in the earth's atmosphere is 392.22 parts per million (ppm) as of October 2011 by the National Oceanic and Atmospheric Administration (NOAA 2011).

CO_2 is an asphyxiating agent and is dangerous to humans in high concentrations. Symptoms of moderate to high CO_2 exposure include dizziness, headache, tingling, difficulty breathing, increased heart rate, coma, and convulsions. Table 2.1 details CO_2 health effects in humans by concentration.

Table 2.1: Impact of Carbon Dioxide on Human Health

CO_2 level in parts per million	**Potential health issue***
250-350 ppm	Background (normal) outdoor air level
600 ppm	Minimal air quality complaints
600-1,000 ppm	"less clearly interpreted" -OSHA
1,000 ppm	Indicates inadequate ventilation; complaints such as headaches, fatigue, and eye and throat irritation will be more widespread; 1,000 ppm should be used as an upper limit for indoor levels
2,000 - 5,000 ppm	Level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
>5,000 ppm	Exposure at this level over an 8-hour period may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death
30,000	Reduced acuity of hearing and increasing blood pressure and pulse from short-term exposure
40,000	Considered immediately dangerous to life and health - NIOSH
50,000	30 minute exposure produces signs of extreme intoxication
70,000-100,000	Unconsciousness within a few minutes - ACGIH

***Data compiled from the Wisconsin Department of Health Services, OSHA, NIOSH, and ACGIH**

In occupied buildings, CO_2 levels in excess of typical and normal ambient conditions are primarily produced by occupant respiration. Poorly designed air conditioning system ventilation and the infiltration of air from streets or parking garages attached to or near the building can create IAQ problems. Previous research associates indoor CO_2 concentrations with "increased prevalence of certain mucus membrane and lower respiratory sick building syndrome (SBS) symptoms" (Apte, Erdmann, Steiner 2002, 443).

Federal IAQ standards for CO_2 and other indoor pollutants are administered through OSHA's PELs. These standards are meant to be absolute limits definitively associated with extreme adverse and identifiable health effects such as death. CO_2's OSHA PEL is 5,000 ppm over an eight hour exposure period (29 CFR 1910.1000 Table Z-1).

No standards exist for acceptable healthy levels of CO_2 in buildings; however guidelines for acceptable levels of CO_2 and other pollutants exist at the state, national, and international levels from public and private entities. State governments such as Texas, Wisconsin, Colorado, New York, and Minnesota have guidelines or public awareness initiatives for IAQ issues. These guidelines often follow industry standards created by standards organizations including the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE) and the American Conference of Industrial Hygienists (ACIH). While none of these guidelines carry the penalty of law, they do offer a starting point for policy makers if governments decide to initiate IAQ regulation.

Incorrect Information

In analyzing CO_2 guidelines used in government and private industry, several seemingly creditable sources were found to misquote or misinterpret guidelines established by standards setting associations like ASHRAE and ACIH as well as regulations set by OSHA.

It was most common to review current research or literature only to find they were based on outdated guidelines as was found in an EPA IAQ educational webpage and an online encyclopedia of building and environmental inspection, testing, diagnosis, and repair called InspectAPedia (EPA, TFS 2011; InspectAPedia 2011). Both these sites quote ASHARE indoor CO_2 levels from outdated versions of the guidelines from 2001 and 1989, respectively.

The Minnesota Department of Health progressively set IAQ workplace safety standards at current OSHA-regulated ceiling limits, but did not reduce these limits when OSHA reduced their limits (MNDOLI 2011). This once progressive regulation of indoor CO_2 limits by the state is invalidated by the higher government's more conservative standard. Another informational website attempted to calculate CO_2 exposure levels as percentages within the overall particulate level in the air. However the site errs in its calculations, defining what should be 1,000 ppm as 10,000 ppm, 2,000 ppm as 20,000 ppm and so on (Xuna 2009).

Because these inaccuracies can lead to misapplications of data, it is important to check the calculations and methods associated with IAQ guidelines and to examine how measurements are taken at buildings with IAQ occupant complaints. A guideline is only useful if it is accurately set at levels verified by field data. Field data, then, must also be accurate to ensure not only the creation of proper guidelines, but to ensure accurate information is conveyed to building managers and researchers on IAQ data collected at sites which could potentially be classified as "sick". It is then reasonable to investigate IAQ datasets to find out if the data is valuable or useful for scholarly research.

Establishing a testable dataset

Indoor levels of CO_2 can vary widely as a function of building occupancy and building ventilation. Ambient CO_2 levels are relatively stable in comparison to indoor levels. The ambient air measurement was used as the independent criterion to test the validity of the TDSHS dataset. Ambient CO_2 levels are closely monitored by federal entities such as NOAA, NASA, and the Department of Energy's Carbon Dioxide Information Analysis Center (NOAA 2011, NASA 2011, CDIAC 2011). NOAA has tracked monthly global CO_2 levels since March 1958, and NASA's Atmospheric Infrared Sounder was launched in 2002 to record satellite imagery of global CO_2 and other trace gases in the earth's atmosphere (NOAA 2011, AIRS 2011).

Even with yearly global carbon emissions at a record 30.6 billion metric tons in 2010, the highest recorded average global ambient CO_2 measurement was 394.16 ppm in May 2011, with a current global yearly average of 392.22 as of October 2011 (International Energy Agency 2011, NOAA 2011). Since NOAA began recording global CO_2 levels, CO_2 has risen from a yearly average of 314.61 ppm in 1958 to 392.22 in 2011 (NOAA 2011).

Indoor air can vary widely in comparison to ambient air. Guidelines state that indoor air can vary from ambient levels by 700 ppm before becoming an issue (ASHRAE 62.1-2010, Persily2002, TDSHS §297.8). Because indoor air levels of CO_2 vary widely and ambient air levels are relatively stable, the ambient air samples should be used to determine overall sample validity.

Conceptual Framework

Analysis of environmental protection policies has found that environmental health regulators should set priorities on the "opportunities for the greatest risk reduction using all the tools available to reduce risk" (Kraft 2011, 221). This policy analysis has found that improving the data and methodologies for risk assessment is paramount in protecting the public through responsible regulatory action (Kraft 2011, 221; National Academy of Public Administration, 2000, 26; EPA 1990, 8). Table 2.2 summarizes components of this exploration in establishing a liberal range for ambient air.

Table 2.2 Conceptual Framework Components

Category	**Sources**	
Established ambient CO_2 as a testable indicator of overall sample validity	ASHRAE 2011 NOAA 2011 NASA 2011 CDIAC 2011 AIRS 2011 IEA 2011	WDSHS 2011 OSHA 1999 NIOSH 1999

Explorative research is considered "preliminary" with no set hypothesis to prove or disprove, just theory "supported with empirical evidence," (Shields and Tajalli 2005, 14). The purpose of this research is to explore the accuracy of data presented in Texas government reports using an established range for ambient CO_2 levels.

Summary

Citizens living in the developed world spend an estimated 90 percent of their time indoors. The air quality of this indoor environment can be impacted by contaminants such as CO_2 because of a socioeconomic trend in energy and cost-effective building practices. These air contaminants build within a closed HVAC system and can be harmful in high doses over long exposure periods. There are currently no regulations set for comfortable levels within buildings, but several guidelines exist. A review of guideline application, however, found cases where the data was misused or researchers and policy makers failed to use current guidelines or update information once new data was available. Because validity of research findings depends on the accuracy of data, it is important to check not only guideline application validity, but the validity of the datasets used in applying guidelines to ensure accurate information is given to the appropriate sources to identify IAQ issues.

Chapter 3
Method

This chapter describes methods of investigating accuracy of IAQ reports prepared by the Texas Department of State Health Services. The following table is referred to as an 'Operationalization Table' because it gives operational value to the investigative points of this research. The table also provides the basic information to assess the accuracy of the TDSHS reports.

Table 3.3: Operationalization of the Conceptual Framework

Dependent Variable	**Definition**	**Measurement**	**Accepted Levels**	**Data Source**
Sample ambient gaseous concentrations of CO_2 found in tested Texas state agency buildings	Levels of airborne CO_2 measured outside sample buildings	CO_2 is measured in Parts Per Million (ppm)	Ambient CO_2 levels should be between 300 and 500 ppm	Samples conducted by TDSHS in 122 sites from 2005-2011 whose results are then compared to a conservative range of ambient CO_2 levels supported by ASHRAE, the CDIAC, NOAA, IEA, and NASA's AIRS

Data Source

Reports for this study were obtained through an open records request from TDSHS. The TDSHS Environmental Hazards Group offers indoor air quality testing upon request to other state agencies. This testing is provided through a mandate in the Texas Government Code Chapter 2165 subchapter G. Indoor Air Quality - Sections 2165.301-305. State building managers must have a formal IAQ concern to warrant an indoor air investigation by TDSHS.

Records for these inspections were available from 2005 through 2011. Tested buildings for a given year varied from seven in 2005 to 39 in 2008. A total of 143 building sites were tested during this time. Of these site testing reports, 122 recorded both the indoor and ambient CO_2 level. Indoor CO_2 was measured in one or more locations within a site for a total of 1,117 individual CO_2 samples in the total data set. This study uses measured data for ambient CO_2 as an indicator of overall data validity.

The CO_2 readings were taken predominately using a TSI Q-Trak IAQ Monitor which is capable of measuring airborne CO_2 concentrations of 0-5,000 ppm with an accuracy of ±100 ppm. The other device used sporadically in measuring this data set was a Quest Technologies AG Series Indoor Air Quality Monitor capable of measuring airborne CO_2 concentrations of 0-5,000 ppm with an accuracy of ±50 ppm. Each site had a number of tested locations inside the building ranging from one to fifty-one. The largest site sample was broken up over two reports.

This data is especially pertinent to the study because although the state has expended funds to conduct hundreds of IAQ site inspections and compile reports on each inspection, no data analysis of these records has been conducted on this dataset. The author of this applied research project is the first person to receive the data through an open record request. Not only is the author the first outsider to examine this data, but no internal examination of this data was ever performed by TDSHS on the IAQ testing data concerning agencies across Texas. This is of note because records for this dataset were recorded yet not retained prior to 2005, creating a larger scale of unanalyzed agency data.

Testing method

To test the ambient air measurements reported in the dataset, NOAA's current world average of 392ppm for ambient CO_2 levels was referenced as a starting point. Based on the general accuracy of TDSHS testing instruments this measurement was rounded up to 400 ppm. Because the TSI Q-Trak IAQ monitor was used predominantly in dataset testing and has the highest accuracy range at ± 100 ppm it was applied to the adjusted NOAA value of 400 ppm to established a typical and normal ambient concentration of CO_2 of 300-500 ppm. ASHRAE guideline calculations directly correlate with this range further supporting the use of this conservative range to test the dataset for measurement accuracies (ASHRAE 62.1-2010, 37). Ambient CO_2 measurements in excess of 500 ppm or below 300 ppm should be considered questionable in the absence of any specific localized or contributing source.

Summary

To assess the accuracy of state IAQ testing, 122 site evaluations conducted by the TDSHS Hazards Group between 2005 and 2011 were analyzed. The site's ambient CO_2 levels were evaluated based on their inclusion or exclusion in a conservative range of 300-500 ppm.

Chapter 4
Results and Discussion

This chapter details the results of 122 CO_2 inspections in Texas state buildings conducted by the TDSHS Environmental Hazards group between 2005 and 2011. IAQ inspection data for ambient CO_2 levels was evaluated within a conservative range of 300-500 ppm to assess the dataset's overall accuracy. Table 4.4 shows the results of this analysis.

Table 4.4: Results

Ambient air concentrations of CO_2 at tested Texas state agency buildings	Results
Between the range of 300-500 ppm	Applies to 84 of the 122 sites, or 68.85%
Total out of range	Applies to 38 of the 122 sites, or 31.15%
Above 500 ppm	Applies to 35 of the 122 sites, or 28.69%
Below 300 ppm	Applies to 3 of the 122 sites, or 2.46%

Based on the conservative range of 300-500 ppm, 31.15% of the overall dataset's ambient CO_2 measurements are out of range and therefore questionable. No data was provided within the individual site reports or with the complete dataset to account for these inaccuracies, and so it must be assumed these out of range measurements were accepted as accurate by the department and by building managers. Table 4.5 shows the out of range data broken down by year.

Table 4.5: Out of range data percentage by inspection year

Year	Inspected	Out of range	Percent of data out of range
2005	5	5	100%
2006	25	23	92%
2007	11	4	36.36%
2008	30	3	10%
2009	19	3	15.79%
2010	20	1	5%
2011	12	0	0%

The complete dataset is found in the Appendix section. The Year column corresponds to the year the report was released to the tested agency site by TDSHS. The location of each tested site is shown with the measured ambient CO_2 level and averaged indoor CO_2 level. All sample sites are in the state of Texas.

Discussion

This research found over 31 percent of all sites tested for indoor and outdoor CO_2 by TDSHS between the years of 2005 and 2011 to be questionable. No information was contained in the reports that would account for these abnormal and/or atypical levels of ambient CO_2.

Measurements at site visits were limited to CO_2 sampling, with occasional limited VOC testing. Visual inspection of the site was conducted by agency employees. No site was tested for all indoor air contaminants or concerns addressed in §297.8.

In this study, site data was considered unusable if the data did not cite an ambient CO_2 level or if the agency employee did not test for CO_2 levels. Of the 20 unusable site visits in the study, half lacked ambient air measurements. This is important because the agency uses a guideline that directly relies on the ambient air level to analyze indoor air samples. Without recording ambient levels, it is not possible to extrapolate guideline adherence.

The highest recorded ambient CO_2 sample from the dataset was 1124 ppm, with the lowest ambient CO_2 sample measured at 109 ppm. When contacted by phone, scientists with the Carbon Dioxide Analysis Center at Oak Ridge National Laboratories affirm that ambient CO_2 levels at 109 and 1124 ppm are not physically possible on Earth. The scientists also assert the range used for this research was very conservative. They suggested the range could be reduced to 350-450 ppm and still be scientifically sound. This range would increase the dataset's overall inaccuracy to 48.36 percent.

In some years most or all the ambient CO_2 measurements showed questionable data. The quantity of questionable data appears to generally decrease from 2005 to 2011, which may suggest that the individuals performing these assessments have received appropriate training and/or that the instruments were gradually appropriately calibrated or replaced over the time period of this study.

Instrument Calibration

One possible explination for out of range ambient CO_2 measurements within the dataset could be that the instruments used were not calibrated approprately. The dataset cites two instrument types used for measurement collection, but does not indicate whether or not these are the two instruments used by the agency or two types of instruments used across the state by inspectors.

The TDSHS Community Hygiene Inspection Manager is responsible for IAQ inspections by TDSHS in public buildings across the state. In a phone interview the Community Hygiene Inspection Manager said that in the years of 2005 and 2006 regional inspectors across the state had CO_2 testing equipment assigned to their location. The manager reported that due to the volume of equipment across the state the, CO_2 instruments were not set to the manufacturer for calibration on any set schedule. The manager said he recalled these instruments in 2007, purchaced new devices, and created a loose calibration schedule for the agency's CO_2 measuring devices. These new devices are now shipped to regional inspectors for use at an inspection site and stored at headquarters.

This centralization of equipment and creation of a loose schedule could be responsible for the increased accuracy seen in the dataset after 2007. The percentage of ambient CO_2 measurements out of this study's range dropped by 55.64 precent from 2006 to 2007.

Personnel Training

Another explanation for the incorrect information found in the reports could be that employees were not properly trained in equipment use and sample interpretation.

Generation of these reports and other IAQ responsibilities are only one aspect of the porifessional job duties of the environmental specialists in the TDSHS Environmental Hazards Group. In a phone interview, the environmental specialist responsible for signing off on all reports in the study said that there are 11 inspector across the state that conduct IAQ measurements at the agency. The environmental specialist said that employee turnover in this area is infrequent, with inspectors trained internally by supervisors. Inspectors are made aware of device manuals and report to regional supervisors and have other job duties not pertaining to IAQ inspections.

The environmental specialist said that he/she and all other staff are generalists with no formal training in ambient or indoor CO_2 issues and do not have access to topical information aside from general EPA guidance documents on IAQ. His/her training in IAQ was recieved at his/her time of hire over 15 years ago. He/she does not recall any additional formal or information training on IAQ testing or interpretation offered by the agency.

Studies in personnel management found productivity gains in businesses operating below expected productivity once employee training programs were implemented (Bartel 1994). Instruments used to measure gaseous levels of carbon dioxide must be calibrated and handled correctly during use. If employees were unfamiliar with the technology associated with their jobs, their work productivity would suffer (Bartel 1994).

Training must come from qualified instructors working as experts who work with learners to "transfer to them certain areas of knowledge or skills to improve in their current jobs" (McNamara, 2007, 1). Yet this training cannot be a singular event. "Development is a brad, ongoing multi-faceted set of activities" that when facilitated correctly bring "someone or an organization up to another threshold of performance, often to perform some job or new role in the future" (McNamara 2007, 1).

In a phone interview, the TDSHS Community Hygine Inspection official indicated that a formal IAQ inspection training program was difficult to find. Employees could contract with private IAQ inspection companies such as the IEE in California or the Indoor Environmental Consultants in Austin. The TDSHS IAQ web site cites partnership with private IAQ compaines for site testing, and so training services are also reasonable.

By implementing initial and ongoing training for its employees, the agency could ensure its employees know how to operate field instruments and interpret their measurements. Ongoing training would provide a culture of learning where employees are able to have access to updated information on instrument use. Using training, employees of this agency could also have reviewed their reports for factual information.

Training on sampling of various gaseous concentrations would allow employees to spot questionable information such as incorrect CO_2 measurements before the information is included in final interagency reports. Training programs therefore will also save or earn the department money if evaluated for financial benefit to the organization (Aguinis and Kraiger 2009).

Employee training can also be evaluated by worker performance measures, which are linked to organizational effectiveness (Aguinis and Kraiger 2009). In the case study, if employees were not trained or trained improperly, a measure of the training's effectiveness could be seen in the worker's job performance, namely their ability to read field instruments and identify accurate information to include in official reports. If reports are consistently false, the effectiveness of the organization is called into question, making a solid training program in this agency directly responsible for organizational effectiveness.

Because employee training programs can increase worker productivity (Bartel 1994) qualified trainers must be sought by the agency to effectively train employees (McNamara 2007). This training should be continual to allow employees to develop a culture of learning sufficient to increase productivity and accuracy in job performance (McNamara 2007). In the case of the agency testing air quality, this training program can be directly linked to organizational effectiveness through employee performance making an effective training program paramount to the agency's goals (Aguinis and Kraiger 2009).

Because worker performance is below the desired level characterized by the years of inaccurate report generation, the agency should create an IAQ inspection training program.

Rectifying inaccurate reports

Though efforts were made to streamline instruments and instrument calibration across the state, no internal review was coducted to identify and retest inaccurate reports within the dataset and inacuracies persisted which invalidated many reports issued by the agency. Interagency relationships and public perception are paramount to an agency's continued credibility and in many cases renewed governmental funding. In Texas, the Sunset Advisory Commission (SAC) regularly assesses a state agency's usefulness. During the review process agencies can be reorganized, missions revised, they can be merged with other agencies, or closed (SAC 2011).

Instances in which entire teams submit inaccurate reports to other agencies can really embarrass an agency and hurt its reputation. Either the agency or the SAC could choose to take steps to publicly condone the work group's behavior. Public disapproval and media attention to the matter could also create negative relations for the agency. Therefore the agency must decide how to handle this situation.

One idea is to fully investigate employee actions internally to assess the issue. Because the infraction deals with a work group and their interactions with many other agencies, the agency should consider setting up an oversight committee to review all work group products. This work group should have a clear chain of command and involve parties from within the agency and from other agencies at the discretion of the presiding official. The agency's commission should be briefed of the committee formation and a deadline should be set for findings.

The agency should work to mitigate any tension between itself and its fellow agencies. These other agencies must be notified in writing of these options. A press release should then be drafted and the marketing and legislative teams in the agency consulted on the best practices associated with handling comments and information inquiries. The agency should designate a spokesperson for the issue and fully brief this person on details of the issue.

By internally managing this multi-person multi-organization issue properly the agency can mitigate negative backlash from the SAC, other agencies and the public. In acting to condone the reporting inaccuracies, the department would show responsibility as it works to restore its credibility with its fellow agencies and the public. TDSHS should prsent this as a solution-oriented problem. Reporting the oversite committee and agency plans for personnel training will show the agency in a forward-thinking role which will go far in showing dedication to rectifying the situation. However, if the agency chooses to ignore the issue the SAC, the public or the media may find fault in agency actions. By failing to condemn and correct the work group's actions the agency opens itself up to further scrutiny which it will not be able to control as effectively.

Recommendations

It is recommended that the state expand this IAQ testing service to include employee training on instruments and testing for a wider range of indoor air health risks or remove this service entirely.

The agency could charge for its services to allow additional program funds to data collection and employee training. According to both agency employees interviewed for this report, the agency is currently considering a charge for its current services and has regulatory authority to do so. To include an expansion of services and employee training would not be unreasonable. Employee training would include instruction on use of current and future instruments and interpretation of measurements taken in the field. An expansion of services could also include testing for more of the IAQ conditions and contaminants listed in the state's Health and Safety Code.

Removing the service could free Environmental Hazards staff to focus on other projects, or if the staff becomes redundant it would allow the agency to redistribute the FTE positions to other more critical programs.

Either course of action would counter the agency output of inaccurate interagency reports.

Appendix

Dataset

Year	Agency	Location	Ambient CO_2 (ppm)	Average Indoor CO_2 (ppm)
2005	HHSC	John H. Winters Bld. ATX	663	1109.4
2005	TCEQ	Building C ATX	557	2128.5
2005	TDSHS	Room T-87- Tower Building ATX	592	938.33
2005	HHSC	Long Term Care 10205 Nlamar ATX	549	1034.57
2005	TEC	Sam Houston State Office Bldg 10th fl ATX	545	745.75
2006	HHSC	4405 Nlamar ATX	525	1110
2006	TBPC	1st fl Bld B TCEQ complex	549	961.66
2006	DHSH	R Bld 1100 W 49th ATX	592	1027.44
2006	TGLO	970 9th & 7th fl SFA bldg ATX	654	1250.63
2006	TBPC	File storage Bld C TCEQ complex	612	12331.33
2006	ASH	Bld 555 HHSC 4110 Guad ATX	684	923.43
2006	TSAO	Robert E Johnson Leg State OB ATX	647	945.72
2006	TSBDE	Hobby SOB #800 ATX	625	893.82
2006	SBVME	Hobby SOB #810 ATX	625	903.13
2006	DARS	Laredo office	436	1132.25
2006	DSHS	ASH bld 552	667	698.43
2006	DSHS	4110 Guad bld 636 ATX	901	950.73
2006	TCPA	SFA SOB ATX	621	935.4
2006	TDARS	Alvin FO	671	964.6
2006	DSHS	Rm T104-111 1100 W 49th St ATX	654	889.17
2006	DSHS	G-308 1100 W 49th St ATX	654	825
2006	HHSC	Decatur office	378	877.5
2006	HHSC	FO Houston	796	1110.9
2006	TCPA	LBJ SOB 10th fl ATX	665	1468.25
2006	TDSHS	M-125 1100 W 49th St ATX	646	1414.67
2006	OAG	5500 E Oltorf ATX	654	1364.1
2006	TLC	REJ Legislative SOB ATX	649	1152
2006	TABC	2nd fl 5806 Mesa Dr ATX	645	1532
2006	TDI	Hobby SOB #220 333 Guad Twr 3 ATX	652	952.33
2006	TSBVI	bld 529, 544, 500, 508 1100 W 45th ATX	642	985.82
2007	TAHC	2105 Kramer Ln ATX	342	788
2007	USBP	ACOASSO Del Rio	233	234
2007	DARS	941 Pleasanton Rd. SATX	135	471.33
2007	TCEQ	14250 Judson Rd SATX	109	501.6
2007	TCEQ	Bld F TCEQ complex ATX	391	697.57
2007	DSHS	M-575 1100 W 45th ATX	355	777.83
2007	DSHS	Tower Bld T-202 1100 W 45th ATX	347	609.4

2007	OAG	5425 Polk St. Htown	715	1226.67
2007	DSHS	M-347 1100 W 45th ATX	366	942.71
2007	TCAD	8314 Cross Park ATX	325	555.5
2007	TYC	2nd fl Brown Heatly SOB suite 2400	379	723.8
2008	TRRC	Corpus Christi	553	798.77
2008	OAG	CSD FO Arlington	471	672
2008	HHSC	Edinburg	720	1326.87
2008	TRRC	9th fl WBT SOB ATX	369	638.75
2008	HHSC	22 Briercroft Office Park Lubbock	360	682
2008	TCSEC	2nd fl Hobby SOB ATX	356	706.64
2008	OAG	WPClements SOB ATX	352	814
2008	TDHCA	SIB Annex 221 E 11th St ATX	401	1019.06
2008	TDFPS	Burnet	371	801.67
2008	TDPS	Region 3 HQ Corpus Christi	462	939.2
2008	ASS	Campus Bld 633	384	583.71
2008	HHSC	11101 Metric Blvd ATX	404	673.28
2008	HHSC	115 W Morris Seymour	460	856
2008	HHSC	1531 Cumberland Vernon	460	856
2008	HHSC	2nd fl Sect F Winters SOB ATX	400	969.06
2008	OAG	CSD 3000 S IH-35 ATX	424	612.05
2008	DPS	Crime Lab bld B HQ ATX	349	542.63
2008	TCEQ	Bld F TCEQ complex ATX	337	820.08
2008	TCEQ	Bld D TCEQ complex ATX	337	649.5
2008	OAG	Call Center bld McAllen	712	2784.44
2008	TCEQ	Bld A TCEQ complex ATX	364	893.56
2008	ASH	Campus Bld 636	471	939.13
2008	TDA	SFA OB 1700 N Congress ATX	369	1004.87
2008	TCEQ	Bld C TCEQ complex ATX	364	1070.8
2008	GLO	SFA OB 3rd fl ATX	348	595
2008	TCEQ	Bld C TCEQ complex ATX	335	645.14
2008	DSHS	6th fl Moreton Bld	406	749.33
2008	HHSC	2nd fl Exchange OB 10205 Nlamar ATX	379	563
2008	TLC	REJ Legislative SOB 2nd fl ATX	383	553.4
2008	DADS	John H. Winters Bld. ATX	381	693
2009	OAG	Texas City	482	1485.86
2009	OAG	Texarkana	504	1574.57
2009	TDI	Warehouse/training 7915 Cameron ATX	357	417
2009	DSHS	WD Carroll 1100 W 49th ATX	354	747.5
2009	OAG	McAllen	712	1863.73
2009	TSCO	LBJ SOB 10th fl ATX	324	1384
2009	TPRB	WBClements SOB	350	737.92
2009	TDI	Hobby SOB Tower I,III ATX	422	643.18
2009	HSWF	1111 N Loop Suite #233 ATX	313	777.3

2009	TYC	HSWF 1111 N Loop ATX	313	536.6
2009	TLC	REJ Legislative OB ATX	365	582.33
2009	TDHCA	Insurance Annex Bld 221 E 11th ATX	358	1059.71
2009	TEA	WBTravis OB 1701 N Congress ATX	343	1043.24
2009	TCEQ	Bld F TCEQ complex ATX	385	854.33
2009	DSHS	Region 8 HQ SATX	389	858.71
2009	HHSC/DFPS	Bunbar Bld Livingston	401	1818.76
2009	TCEQ	Bld C TCEQ complex ATX	321	618.88
2009	TDPS	McAllen	980	1341.8
2009	DARS	FO 3721 Briarpark Htown	412	1027.92
2010	TCEQ	Bld E TCEQ complex ATX	349	642
2010	OAG	Child Support Harlingen	1124	2596.3
2010	SORM	WPClements SOB ATX	356	1054.5
2010	OAG	Austin Child Support 1616 Headway ATX	313	1717.21
2010	TDI	DWC 7551 Metro Center Dr bld 10 ATX	330	430.88
2010	TCEQ	Bld A TCEQ complex ATX	330	2707.5
2010	TCEQ	Bld E TCEQ complex ATX	320	619.83
2010	TCEQ	Bld C TCEQ complex ATX	346	1126.43
2010	OAG	CPD 300 W 15th ATX	375	590.63
2010	DARS	Rosenberg	420	959.17
2010	THHSC	Region 8 Schertz	370	1443.88
2010	TEA	WBTravis OB 1701 N Congress ATX	425	915.6
2010	OAG	Child Support Laredo	330	1042.58
2010	HHSC	9460 Harwin Houston	385	574.78
2010	HHSC	9450 Harwin Houston	387	1141.62
2010	DSHS	Region 10 401 E Franklin El Paso	302	490.42
2010	TSTC	Bld U Harlingen	361	1050.5
2010	OAG	Child Support Arlington	432	715
2010	HHSC	Tri County bld Cleveland	370	999.69
2010	HHSC	2711 Little York Houston	389	869.06
2011	HHSC	4105 Victory Marshall	421	1317.33
2011	HHSC	205 Kimberly Cleburne	406	670
2011	MS	Supported Living Center Mexica	416	981.43
2011	MS	Supported Living Center Mexica	399	717.63
2011	THHSC	Region 8 Floresville	390	898
2011	TPWD	858 W Rhapsody SATX	396	1151.6
2011	HHSC	1202A E Sam Rayburn Bonham	422	861.25
2011	HHSC	1950 Clear Lake Weatherford	322	963.88
2011	HHSC	Raleigh SOB 5th fl ATX	354	677.11
2011	DSHS	300 Campbell Cleveland	355	783.25
2011	TDPS	Rio Grande City FO	396	916.1
2011	TWDB	SFA SOB ATX	388	669.6

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