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Qualitative measurements of occupant comfort in five U.S. schools

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Qualitative Measurements of Occupant Comfort in Five U.S. Schools

by

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List of Abbreviations & Acronyms

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CIE	EPA Center for Indoor Environments
EPA	U.S. Environmental Protection Agency
EPC	Energy Performance Contracting
ESCOs	Energy Service Companies
HVAC	heating, ventilating, and air conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
NAESCO	National Association of Energy Service Companies
R&IE	Radiation and Indoor Environments National Laboratory
UNLV	University of Nevada Las Vegas

Abstract

The United States Environmental Protection Agency (EPA) performed indoor air quality studies in five U.S. schools during energy retrofits during 1997-98. Four EPA reports and three Environmental Health and Engineering, Inc. (EH&E) reports illustrated the indoor environmental quality before and after heating, ventilation, and air-conditioning (HVAC) retrofits at specific elementary schools in Texas, Colorado, Minnesota, New Jersey, and California. Selected comfort, environmental, physical, and occupant response data were collected in randomly selected areas over a one–week, five–school day monitoring period for each of these schools.

The EPA studied indoor air quality (IAQ) and occupant comfort using an EPA Indoor Environmental Quality Survey. The questionnaire asked the building occupants at the schools about how they thought their building environment and work affected them. Within in the school building studies, the EPA measured sound, indoor temperature, relative humidity, continuous light, airborne particle concentrations, individual volatile organic compounds (VOC's), formaldehyde, particulates, bacteria and fungi, radon, carbon monoxide, and carbon dioxide. Selected comfort, environmental, and physical data were collected in selected areas over a three contiguous school day monitoring period. A baseline and follow-up study was conducted for each school. Survey information possibly suggests that occupant comfort improved after HVAC retrofits, albeit the findings are inconclusive.

The focus of the paper was to determine if occupant comfort improved, decreased, or remained neutral after energy retrofits in the five U. S. schools. Selected measurement data and applicable questionnaire data was summarized for each school and then compared between the pre-study and the post study years.

Introduction

The purpose of this thesis was to determine whether occupant comfort improved, decreased, or remained neutral after energy retrofits in five United States school buildings. The thesis answered: to what extent did occupant comfort (measured by data from surveys and reports) change after energy retrofits were performed in five different United States school buildings? The study identified the preexisting and post- retrofitting indoor air quality in the school buildings and examined whether recommended changes in the heating, ventilating, and air conditioning (HVAC) systems changed the comfort levels of the school building occupants.

The United States Environmental Protection Agency (EPA) mission is to protect public health and the environment. An important goal of the EPA Radiation and Indoor Environments National Laboratory (R&IE) is to improve indoor air quality (IAQ) in schools across the United States. The EPA developed a program called "Tools for Schools" guidance, in conjunction with the American Federation of Teachers, the Association of School Business officials, the Council for American Private Education, the National Education Association, and the American Lung Association (US EPA, 1995). This guidance is a set of guidelines that was designed by the EPA to assist educators in preventing and solving the majority of indoor air problems with minimal cost and involvement by using school staff to perform a limited and well defined set of basic operations and maintenance activities.

When further renovations to a building are needed (other than operations and maintenance), another way to potentially improve indoor air and to use energy efficient equipment to recoup costs is Energy Performance Contracting (EPC). Essentially, EPC is the acquisition of comprehensive capital energy improvements and services provided by qualified Energy Service Companies (ESCOs), where the energy and cost savings achieved by the

installed energy project are used to pay for the project. (Birr & Donahue, 2001). EPA's R&IE collaborated with Honeywell Inc., Home Building Control as part of a 3-year cooperative agreement with the National Association of Energy Service Companies (NAESCO) where the EPA performed demonstration projects in schools across the country. It was anticipated that EPA's mechanism for reducing energy consumption, and improving the overall building infrastructure of the school would potentially improve indoor air quality (EPA 2001). The design of the EPA school study did not specifically measure for all occupant comfort parameters. Data was collected that possibly could be sufficient to determine if the recommended retrofits made a noticeable difference in occupants perceived comfort level Comprehensive indoor air sampling in the EPA five school projects have already been conducted for indoor environment quality. The part of the study that is most notably missing is information concerning occupant comfort. The EPA and EH&E reports on occupant comfort were limited so it is expected that the EPA could benefit from this thesis because of the added value of conclusions on occupant comfort.

Indoor environmental conditions, including temperature, affect occupants' perception of comfort. Studies show that occupant comfort in buildings is related to occupant performance (Bearg, 1993). Temperature is important because it is likely that it is a major factor in the comfort and performance of a building's occupants (McCartney 2002). Thermal sensation complaints are the single most common problem of any type reported by occupants in field studies conducted by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). Federspeil (1998) studied complaints from nearly 24,000 occupants in 690 office buildings and found that the complaints were mostly the result of poor control performance and HVAC system faults rather than individual differences in preferred temperatures. Practical implications of these relationships are important, as there is now a

general agreement that office environments influence productivity output of their occupants. While most people are able to maintain high productivity for a short time under adverse conditions, there is a temperature/time threshold when productivity rapidly decreases (Lorsch and Abdou, 1994). Improvements to indoor environmental conditions may, on the other hand, increase productivity in the order of 16% as reported by Kroner and Stark-Martin (1994). Lorsch and Abdou (1994) concluded that since the cost of the office workers is an order-of-magnitude higher than the cost of maintaining and operating the building, spending funds on improving the work environment may be the most cost-effective way to improve worker productivity.

Humidity and humidification equipment affect occupants' perception of comfort level. Humidity is important because the lack of operation of humidifiers can adversely affect the comfort of individuals in buildings where outdoor conditions are cold and dry (Bearg, 1993). Supplying adequate ventilation is important for diluting airborne concentrations of indoor pollutants that may build up due to materials in the space, occupant activities, or occupants themselves (U.S. EPA 2001a). Particles are an important category of indoor air pollutants because at high concentrations they may act as irritants to the eyes, skin, and respiratory tract (U.S. EPA 2001b). Health effects from exposure to Volatile Organic Compounds (VOCs) at concentrations greater than 1,000 times the typical indoor/outdoor levels may cause adverse health effects (U.S. EPA 2001c). Biological contaminants such as bacteria and fungi can contribute to building occupant discomfort. As a result of exposures to microbiological agents, hypersensitive building occupants may experience a variety of health effects ranging from eye and throat irritation to allergic reactions and asthma (U.S. EPA 2001d). If Carbon monoxide (CO) is present in the air it can be deadly, but at lower concentrations health effects may include weakness, dizziness, and headaches.

Approach/Aims

The occupants of a building represent a significant potential source of information for this school building study. Everything people say is a potential clue as to what is going on with the building and its systems (Bearg, 1993). The EPA had previously administered extensive surveys to each of the five schools involved in the study. These surveys helped to answer the question of building occupant comfort changes due to energy retrofits. Indoor air sampling and ventilation rate monitoring was conducted at each school. Results from this sampling and monitoring helped to determine if occupant comfort changed from pre to post retrofits.

Specific objectives of this study are as follows:

1. The results in the EPA surveys provided valuable information for evaluating facility investments. From the surveys, occupant comfort levels were evaluated from pre to post retrofits and determined if there was any changes.
2. The results in the EPA and EH&H reports provided valuable information for evaluating facility investments. From the reports, occupant comfort levels were evaluated from pre to post retrofits and determined if there was any changes.
3. Summarize existing information on the relationship between occupant comfort and building conditions and occupant symptoms.

By analyzing the data in the surveys and reports, I expected to find that energy retrofits in the five school buildings did improve the comfort level of the building occupants. This is a reasonable hypothesis since it was my expectation that improvements to HVAC systems would produce favorable results for occupant comfort.

Methods

Surveys

By means of EPA Environmental Quality Surveys, the EPA and EH&E have produced data of occupant comfort levels for pre and post energy retrofits in five United States school buildings. With each implementation, facilities professionals have found the occupant satisfaction surveys to be useful. Example pages of the surveys used are shown in appendix A. A total of 731 surveys for all five schools are held in reserve in the library at the EPA Center for Indoor Environments in Las Vegas, NV. Obtaining information from the EPA surveys for use of an academic study required the approval of the University of Nevada Las Vegas (UNLV) Office for the Protection of Research Subjects and an assurance-training certificate was obtained. A copy of the certificate is provided in appendix B. Each of the schools had a different amount of surveys depending on the size of the school and the availability of participants. The amount of surveys per school is displayed in Table 1.

Table 1. Total of EPA Indoor Environmental Quality Surveys Administered

	Baseline/Year1	Follow-up/Year2	Total
California	40	24	**64**
Colorado	61	62	**123**
Minnesota	55	47	**102**
New Jersey	194	167	**361**
Texas	50	31	**81**
Total	**400**	**331**	**731**

The EPA surveys were read and analyzed to find what questions asked of the survey participants were applicable to perceived occupant comfort. The baseline and follow-up surveys covered four general areas of inquiry:

1) Workplace Information

2) Information about Health and Well-Being

3) Description of Workplace Conditions

4) Characteristics of Job

After analyzing the surveys, the questions in the Information about Health and Well-being and the Description of Workplace Conditions sections appeared to be the most relevant to occupant comfort relating to HVAC systems. All applicable data from the surveys were entered and organized in Excel spreadsheets for further evaluation and graph generation. The symptoms and conditions used for the occupant comfort study located in the information about health and well being category include:

Symptoms

- dry, itching, or irritated eyes
- wheezing
- headache
- sore or dry throat
- unusual tiredness, fatigue, or drowsiness
- chest tightness
- stuffy or runny nose, or sinus congestion
- cough
- sneezing

- dizziness or lightheadness

Conditions

- too much air movement
- too little air movement
- temp too hot
- temp too cold
- air too humid
- air too dry
- unpleasant chemical odors
- other unpleasant odors

Reports

The EPA Center for Indoor Environments (CIE) detects and measures indoor air quality factors that possibly could affect perceived occupant comfort, these factors include: temperature, relative humidity, and ventilation rates. Four EPA reports and three EH&E reports illustrate the indoor environmental quality before and after HVAC retrofits at elementary schools located in California, Colorado, Minnesota, New Jersey, and Texas. Selected comfort, environmental, and physical data were collected in randomly selected areas over a three contiguous school day monitoring period for each school. EPA and EH&E reports for each school provide an overview and summary of results found during the follow-up study and comparisons of results between the pre and post-study weeks (EPA 2001). These reports were used to obtain information necessary for defining occupant comfort and drawing conclusions on occupant comfort. The EPA and

EH&E reports were read and analyzed to find applicable data that needed to be collected. After analyzing the reports, the sections in ventilation and thermal comfort appeared to be the most relevant to occupant comfort relating to HVAC systems.

Ventilation

Ventilation data was obtained from four of the five participating schools for the pre and post studies. ASHRAE has defined a range of acceptable reference levels for ventilation rates. Data from the EPA reports were used from tables that displayed humidity, temperature, and maximum vertical air temperature. Results from the baseline tables were then compared with the results from the follow-up studies tables. During the course of the study, it was found that certain sites in the schools had inoperative HVAC systems, so the ventilation for those sites was considered zero.

Temperature and Humidity

Data from the EPA reports were used to compare the pre to post retrofit temperature and humidity levels measured in the schools. The thermal comfort data from the school studies were compared to the ASHRAE standard for evaluation. ASHRAE has defined a range of acceptable reference levels for humidity and temperature referred to as the thermal comfort envelope. ASHRAE Standard 55-1992 specifies conditions or comfort zones where 80% of sedentary or slightly active persons find the environment thermally acceptable.

Table 2 is a summary of the ASHRAE recommended thermal comfort envelope. This table can be used to compare the temperature and humidity data results between Year 1 and Year 2 of the data from the EPA and EH&E reports.

Table 2. Summary of Recommended Thermal Comfort Envelope. ASHRAE 55-1992

Relative Humidity	Winter Season	Summer Season
30%	20.2°C - 24.4°C	23.3°C - 26.6°C
40%	20.2°C - 24.1°C	23.3°C - 26.3°C
50%	20.2°C - 23.6°C	23.3°C - 26.1°C
60%	20.2°C - 23.3°C	23.3°C - 25.5°C

Procedure/ Materials, measurements, and apparatus used

A personal computer along with Microsoft Word and Microsoft Excel software, were used to record and display the data and graphs. A Hewlett Packard 9100C digital sender and ScanJet 4c were used to import documents such as reports, surveys, and other documents into this report. All data from reports and surveys were entered and organized in Excel spreadsheets for further evaluation. With data from reports and surveys, graphs and charts were then created using Microsoft Excel. Graphs and charts were used to analyze data from reports and surveys and compare the results between the baseline and follow-up studies of the five U.S. schools. Conclusions were then determined and written about perceived occupant comfort.

Validity and reliability of measurements

The questionnaire data showed some significant decreases in symptoms prevalence between the pre-energy retrofit and the post-energy retrofit studies. However, not all symptoms were alleviated for every school. Although the surveys were numbered consecutively, it should be noted that the surveys could not be matched up between pre and post studies for each individual survey participant. Also for some of the schools the baseline questionnaires out numbered the follow-up questionnaires. The schools were measured for different comfort

parameters in different rooms in the school buildings, however surveys did not reflect that rooms were separated from the school building as a whole.

Results/Data Analysis

Results of Questionnaire Data

Survey results indicate an improvement in overall occupant satisfaction with comfort and health symptoms potentially related to IEQ, with exceptions in a limited number of conditions at the Colorado and New Jersey schools and a limited number of symptoms at the Colorado, Minnesota, and Texas schools. Surveys indicate an increase in wheezing in Colorado, Minnesota, and Texas. According to survey results chest tightness increased only in the Colorado school. According to the survey results dizziness increased in the Colorado and Minnesota schools, with Minnesota having the largest increase.

Occupant survey results show a limited number of negative building condition responses in the Colorado and New Jersey schools, with Colorado having the largest number of occupants perceiving building conditions such as temperature too cold, air too humid, and unpleasant odors increasing in the second year. New Jersey results displayed an increase in the temperature being too hot, air too humid, and unpleasant chemical odors increasing. The questionnaire results used for occupant comfort for each individual school are graphically summarized in appendix C. The graphs in figures 1 through 4 represent comparisons of conditions and symptoms of all five of the pre and post-retrofitted schools. Figures 1 and 2 show a percentage of change from pre to post studies for building conditions and building occupant symptoms. They also show a combined average of percentage change for symptoms and conditions from baseline and follow-up studies.

Figure 1. Percentage of change from pre to post studies for building conditions.

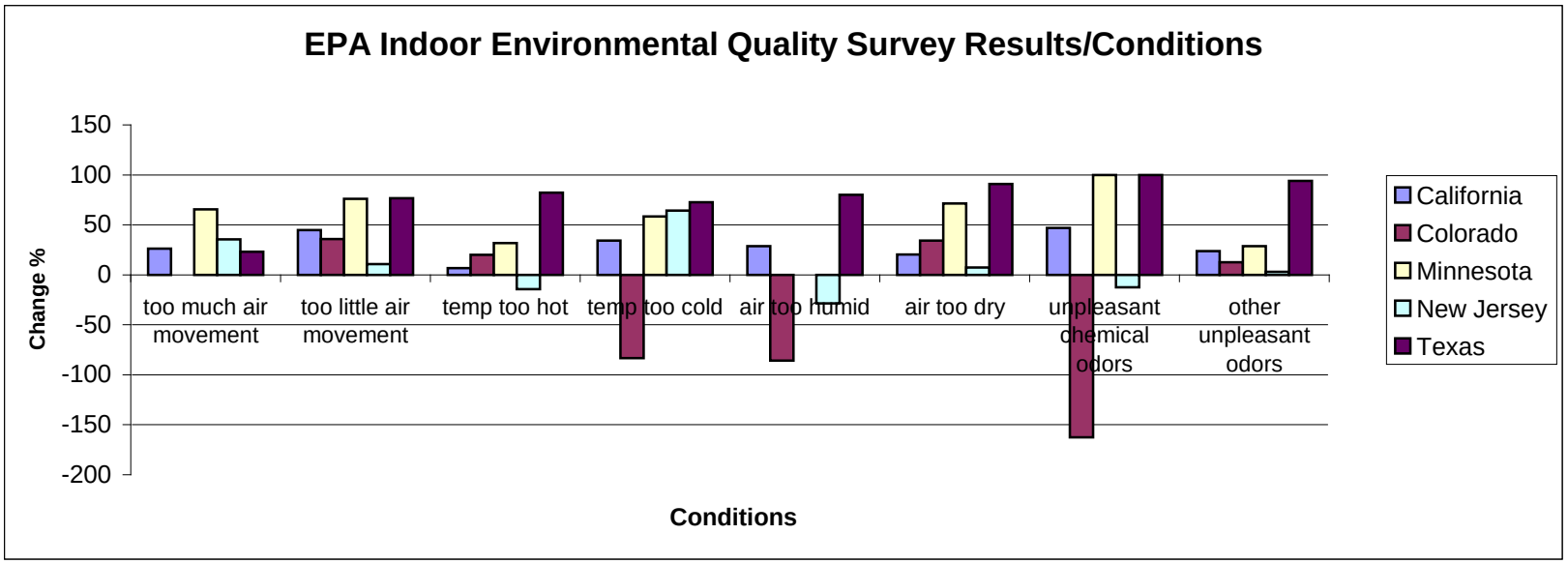
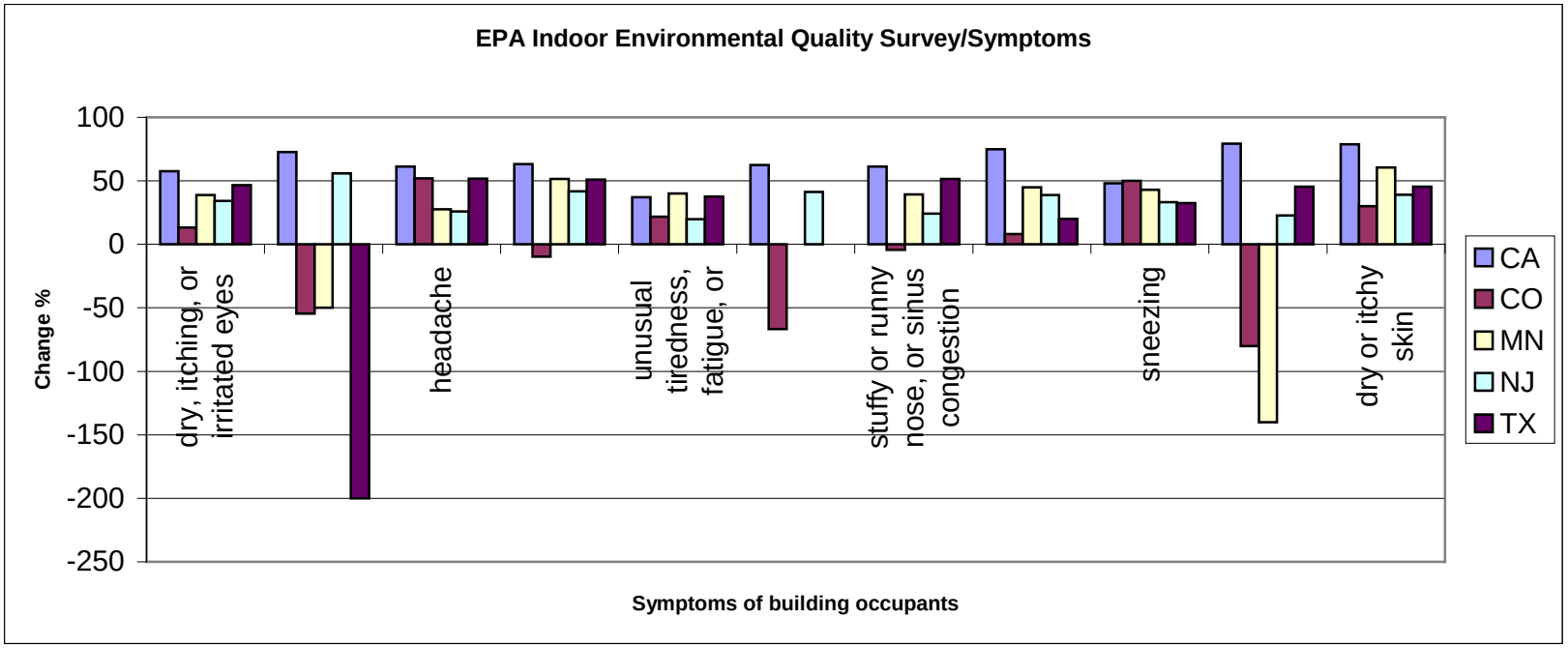


Figure 2. Percentage of change from pre to post studies for occupant symptoms.



Values above the 0 line represent positive change while values below the 0 line represent negative change. The formula used is: Year 1 – Year 2/Year 1=% change.

Figure 3. Combined averages of change from pre to post studies for building conditions.

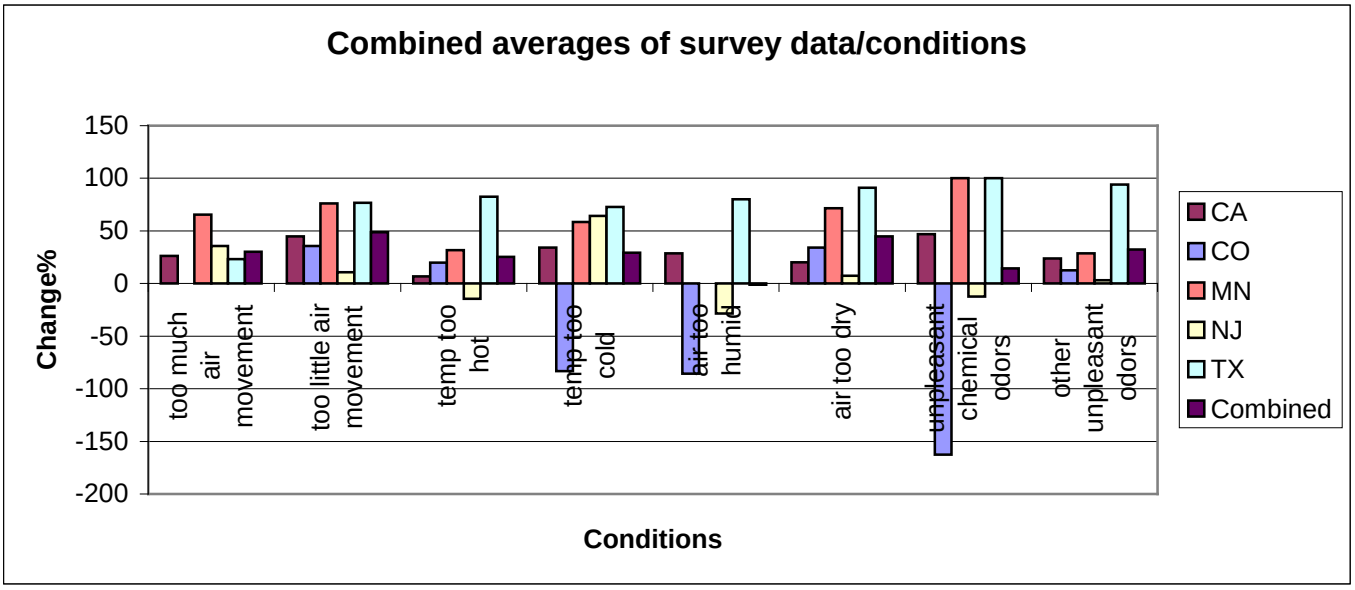


Figure 4. Combined averages of change from pre to post studies for occupant symptoms.

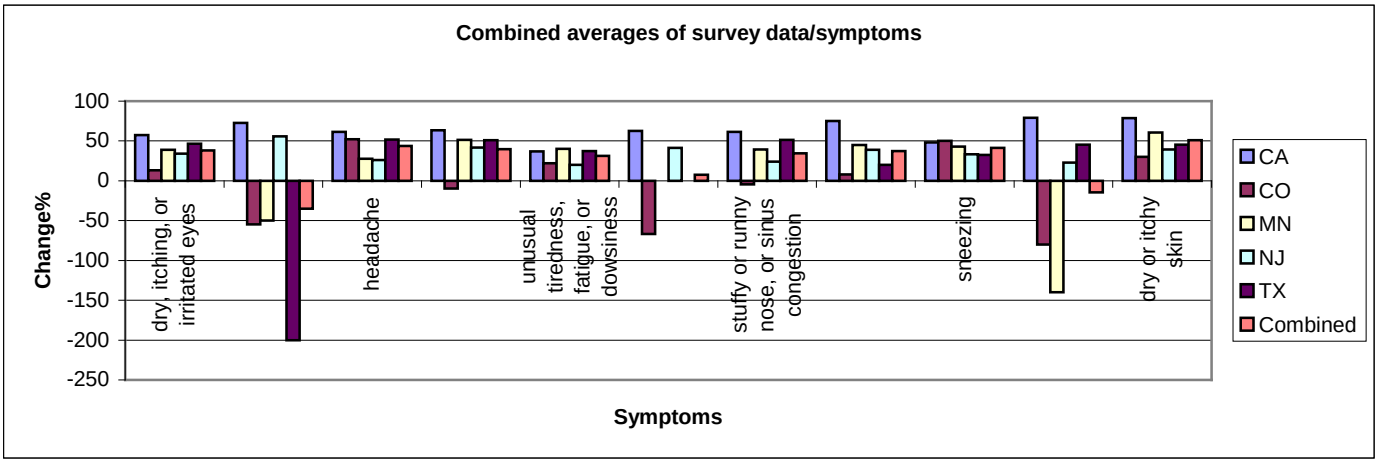


Table 3. Percent Difference of IEQ Survey Results of Conditions and Occupant Symptoms

Survey Conditions	States Where Schools Were Studied				
	CA	CO	MN	NJ	TX
too much air movement	26	0	66	36	23
too little air movement	45	36	76	11	77
temperature too hot	7	20	32	-14	82
temperature too cold	34	-83	58	64	73
air too humid	29	-86	0	-29	80
air too dry	20	34	71	7	91
unpleasant chemical odors	47	-163	100	-12	100
other unpleasant odors	24	13	29	3	94
Survey Symptoms					
dry, itching, or irritated eyes	58	13	39	34	47
wheezing	73	-55	-50	56	-200
headache	61	52	28	26	52
sore throat	63	-10	51	42	51
unusual tiredness, fatigue, or drowsiness	37	22	40	20	38
chest tightness	63	-67	0	41	0
stuffy or runny nose, or sinus condition	61	-4	39	24	51
cough	75	8	45	39	20
sneezing	48	50	43	33	32
dizziness or lightheadedness	79	-80	-140	23	45
dry or itch skin	79	30	61	39	45

This table displays the EPA Indoor Environmental Quality Survey data as percent difference between Pre and Post studies. 100 (Year 1 – Year 2/Year 1)=% difference.

Results of EPA reports

Table 4 displays the average temperature and relative humidity measurements for both the pre- and post-study weeks for all five-study schools. The temperature and relative humidity were within ASHRAE comfort envelope standards for both baseline and follow-up studies

Table 4.

Results of Baseline and Follow-up Temperature and Relative Humidity					
Average Temperature (°C) / Average Humidity (%)					
	CA	**CO**	**MN**	**NJ**	**TX**
Baseline	**22°/28%**	**23°/26%**	**23°/25%**	**22°/34%**	**23°/43%**
Follow-up	**23°/37%**	**25°/30%**	**23°/41%**	**23°/45%**	**23°/53%**

Table 5.summarizes the operating status of HVAC systems in the five schools for the follow-up study.

Table 5. Operable systems in the five schools given for year two of the study.

School	***System Broken***	***Operating System Provides Zero***	***ASHRAE Met***	***Operating no AHRAE standard met***	***Total Sites***
California	**0**	**1**	**1**	**2**	**4**
Colorado	**2**	**0**	**1**	**1**	**4**
Minnesota	**1**	**3**	**0**	**0**	**4**
New Jersey	**1**	**0**	**unknown**	**unknown**	**4**
Texas	**0**	**0**	**0**	**4**	**4**

Discussion/ Conclusion

School building occupants were provided surveys to determine their perception of the environmental quality of their school building. From the survey data collected it appears that occupant comfort improved after the HVAC energy retrofits in the five U.S. schools. Although the data, in the form of graphs, reflect significant improvement in occupant comfort, there are many other variables that affect occupant comfort. The survey asked subjects about their perception of building conditions and symptoms they experienced. Two problems with perceived effects are: every person perceives comfort differently and particular pollutants causing symptoms may differ among schools.

Some of the ventilation systems in the study schools were not operating properly for the follow-up studies. For the most part ventilation rates in the post studies did not meet minimum ASHRAE guidelines, and this could be related to the negative questionnaire responses in some of the schools. If HVAC systems are not operating properly it is hard to tell whether energy retrofits caused a negative, positive, or no effect on occupant comfort. It is clear that commissioning of HVAC systems should be implemented to ensure that the schools provide necessary ventilation.

Trends observed in the questionnaire data indicated that the frequency of reporting overall symptoms from there-energy retrofit to the post-energy retrofit study weeks in the five schools for all of the ten symptoms selected for this study. According to the survey data the eight selected building conditions also improved overall from the baseline to follow-up studies. Although this suggests that the decreases in symptom prevalence and improvement of building conditions were because of the energy retrofits, reasons for these decreases and improvements are not apparent.

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Conclusions are those of the author and do not necessarily reflect those of the EPA or UNLV.

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