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Final Report

Mathematical Model Estimating Mercury Thermostats in Commercial Buildings

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Local Hazardous Waste Management Program in King County
Technical Assistance Pollution Prevention

This report was prepared by the Local Hazardous Waste Management Program in King County, Washington. The program seeks to reduce hazardous waste from households and small quantity generator businesses in King County by providing information and technical assistance to protect human health and the environment.

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ABSTRACT

A research study to estimate the number of mercury thermostats in commercial buildings in King County was conducted in 2005 by the Local Hazardous Waste Management Program in King County. Data was obtained from the 30,975 commercial building assessment records in the 2004 and 2005 King County Assessors Office Commercial Buildings Database and study data collected from 346 sample sites. A mathematical model using predictive statistical relationships was developed as part of the study. Regression analysis and proportional attribution techniques were used to estimate the total number of mercury thermostats. The arithmetic mean for the number of ampoules observed was used to estimate the pounds of mercury.

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INTRODUCTION

Mercury is used in industry processes because of its diverse properties as a component in product ingredients or in industrial processing. Although industrial demand for mercury has declined in recent years due largely to the elimination of mercury additives in paints and pesticides and the reduction of mercury in batteries, it continues to be used in many commercial and consumer products.

A substantial amount of mechanical switches contain mercury and are still found in many types of products, including thermostats. Through end-of-life replacement and building remodeling or demolition, mercury-containing thermostats can enter the waste stream. National and local efforts to further eliminate sources of mercury have identified mercury-containing thermostats as a significant source of mercury in many states, including Washington, making mercury thermostats a high priority for collection and reclamation

Included in the long-term effort to reduce mercury emissions in King County, the Local Hazardous Waste Management Program in King County (LHWMP) conducted the Mercury Thermostat Research Study in 2005. The focus of this study was to determine reliable estimates of the number of mercury thermostats in King County commercial properties and the variables associated with mercury thermostat use. Results from this study will be used to identify cost-effective options to reduce mercury emissions through material substitution and end-point disposal options that encourage product recycling.

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MERCURY EXPOSURE RISK

Mercury in the Environment

Mercury occurs in the environment naturally as metallic (the purest form of mercury that is not combined with other elements), inorganic, or organic. Inorganic mercury occurs in the environment when mercury combines with other elements such as chlorine, sulfur or oxygen. When mercury combines with carbon, organic or organomercurial compounds are formed in the natural environment.

Mercury can also occur in the environment from anthropogenic sources such as from industrial releases and mercury-containing products disposed to landfills. For example, metallic (elemental) mercury is the liquid metal used commonly in thermostats and other mechanical switching devices because of its ability to remain in liquid form at room temperature. However it's these same properties which allow the mercury to readily evaporate to the air and the environment.

Atmospheric Mercury

As a result of natural and anthropogenic activities, mercury cycles in the environment where it can remain for long periods of time. Atmospheric mercury is predominantly composed of elemental mercury vapor that can circulate in the atmosphere for up to a year. Often transported miles from the emission source, atmospheric mercury is deposited to water or soil (Keating, 1997).

Approximately 80% of the mercury released into the environment from anthropogenic activities is elemental mercury. Approximately 15% of the total mercury released is deposited to soil and from municipal solid waste (ATSDR, 1999) which includes the disposal of mercury-containing thermostats to the landfill. The amount of mercury that naturally exists in any one place is usually very low. In contrast, as a result of anthropogenic activity, mercury found in soil at a contaminated site can be well over 200,000 times the naturally-occurring levels.

Methylmercury Toxicity

Mercury deposition influences the most susceptible ecosystems with piscivorous birds and mammals more highly exposed at the top of the food chain. Mercury deposits in the aquatic environment are converted by microorganisms through methylation to methylmercury (MeHg). Through MeHg biomagnification throughout the food chain, it reaches it's most toxic concentration in larger longer-lived species, some of which are consumed as food by humans (Goyer, 2000).

Among humans and wildlife that consume fish, methylmercury is the predominant chemical species contributing to mercury exposure. Methylmercury can bioaccumulate in human tissue, where acute and chronic exposures can produce adverse health affects.

Methylmercury is classified by the Environmental Protection Agency (EPA) as a Group C possible human carcinogen.

Persistent and Bioaccumlative Toxins

Due to the persistent, bioaccumlative, and toxic nature of mercury in the environment, in Washington State, mercury was selected as the first priority pollutant to be addressed in the state's Persistent and Bioaccumlative Toxins (PBT) Reduction Strategy (Gallagher, 2000). From this initial mercury reduction strategy the Washington State Mercury Chemical Action Plan (CAP) was developed in 2003 by the Washington State Department of Ecology (Ecology) and Health (DOH) (Peele, 2003).

The Mercury CAP identified anthropogenic sources of mercury released into Washington's environment at an estimated rate of 3,800 to 5,000 pound annually. Estimated mercury releases from the most common mercury containing products, which includes wall thermostats with an estimated 412 pounds of mercury disposed of as solid waste per year.

Routes of Exposure

The primary routes of human exposure to mercury come from eating mercury-contaminated fish, inhaling mercury vapor from liquid-mercury spills and through dermal absorption from contact with liquid mercury. In a non-industrial setting, children have the highest exposure risk to mercury.

Mercury-Contaminated Fish

The populations of greatest concern with respect to exposure to mercury-contaminated fish are women of child bearing age and children. Through the consumption of mercury-contaminated fish, 90 to 100 percent of MeHg is absorbed through the gastrointestinal tract where it easily enters the bloodstream and distributes throughout the body. MeHg is transported across the blood-brain barrier by an amino acid carrier and readily accumulates in the brain. It can also cross the placenta where it accumulates in fetal tissues.

Although MeHg is distributed throughout all organs in the body, as a neurotoxin the most pronounced effect is on the developing brain of a child with the potential for neurodevelopmental effects that are more diffuse and extensive than the effects seen in the adult brain. Although there are historical examples of high-dose chronic and acute MeHg poisonings, they appear to be uncommon. Mercury poisoning in children is most commonly the result of consuming foods, primarily fish, which are contaminated with MeHg.

Exposure Risk from Mercury Spills

In mercury thermostats, the mercury is completely enclosed and does not pose an immediate threat to human health or the environment. Health exposure risks occur only if the glass ampoule breaks. Should a mercury spill occur metallic mercury is often difficult to remove from many types of materials and surfaces where it can remain for months or years as a continuing source of mercury exposure. Exposure to mercury and mercury vapor can be immediately toxic and can bioaccumulate in human tissue.

Commercial buildings that contain mercury thermostats are often accessible by children. Elementary, junior and senior high schools, churches and day cares are all examples of commercial buildings that can contain mercury thermostats. Through intentional tampering or accidental breakage, children can easily become exposed to mercury.

Since metallic mercury readily volatilizes at room temperature, the most important route of exposure to metallic mercury is through inhalation. Children and adults who regularly occupy a space containing spilled mercury that was not adequately removed are at risk for long-term exposure and associated health risks.

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MERCURY AND NON-MERCURY THERMOSTATS AND SENSORS

Thermostats are used in residential and commercial buildings to control the temperature of an entire building or of an individual space within the building. Generally there are two purposes why temperature is controlled. Either for the comfort of the occupants or for the climate control of a space used for a specified purpose.

Spaces that are temperature controlled for comfort will generally have thermostats located in occupant areas. Thermostats are set for the comfort of the occupants. If it is a large space, more than one thermostat is usually installed. A space (zone) will be regulated by the thermostat that is set to control the temperature in that specific zone. Often different types of thermostats are in use in the same space if the space has been partially remodeled or if different thermostats are more efficient for different zones.

Spaces that are climate controlled will generally have thermostats that are durable and control the temperature of a space at a constant rate. Examples of a climate controlled area would be document storage, equipment, and refrigeration rooms. Dependant on specific temperature needs, the thermostat is frequently located in areas not generally associated with comfort control. For example, a ceiling mounted heater in a large warehouse structure could have the thermostat mounted on the heater itself or mounted high on a nearby post or wall. These types of heaters are commonly installed to provide ceiling heat to warehouse building pipes to prevent freezing and are not installed for occupant comfort.

Mercury Thermostats

The most common mercury thermostat contains an electromechanical on/off switch that is set manually to a single temperature set point[1]. The switch that controls a heating or cooling system is activated by temperature changes. The sensing element is usually a spiral bimetallic strip (Figure 1) that expands or contracts in response to temperature changes because of the differential expansion of the two bonded metals. In a mercury-switch thermostat, liquid mercury rolls between contacts in one or more sealed glass ampoules, which are attached to a bimetallic strip. The switch works when the mercury makes (cut-in) or breaks (cut-out) an electrical circuit, creating a signal to the heating or cooling system. When the temperature reaches the cut-in state the thermostat is fully on and fully off when it reaches the cut-out state. Temperature states of fully on or fully off can create a temperature swing that results in inefficient heating and cooling. For this reason, some electromechanical mercury thermostats also contain an anticipator control (wire loop resistor) that can turn heating or cooling equipment on/off prior to the actual

[1] Manufacturer and distributor technical data and information used in describing thermostat types and functions.

cut-in/cut-out points of the thermostat reducing the magnitude of temperature swing for increased efficiency.

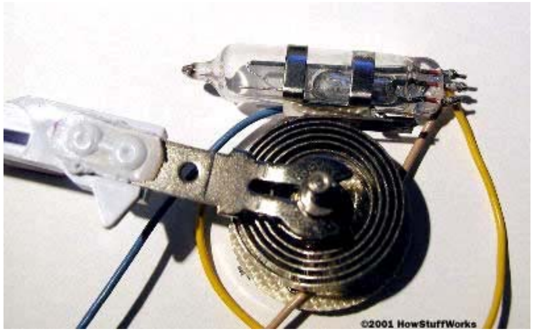

Figure 1. Mercury Ampoule with Spiral Bimetallic Strip Sensing Element

Mercury's unique properties (high conductivity, high surface tension and liquidity at room temperature) make it a useful component in many electric switches. Each glass ampoule contains approximately three grams of metallic (elemental) mercury with each mercury thermostat containing from one to six glass ampoules of mercury (3-18 grams of mercury) dependant on single stage or multistage applications. Thermostats are installed in the area they regulate, most often on a wall or the heating and cooling equipment itself. Mercury thermostats operate quietly, require little maintenance, and provide up to 30-40 years of service.

Non-Mercury Thermostats

Electromechanical

Commonly, non-mercury electromechanical thermostats utilize a snap-action on/off switch with conductive bimetal construction. The bimetallic element carries the circuit current under short circuit conditions with quick make/quick break switching action. Other than the switching mechanism, both mercury and non-mercury electromechanical thermostats maintain similar specifications and applications for use.

Digital

Digital thermostats often utilize a thermistor (resistor) or other integrated circuit sensors whose electrical resistance changes with temperature. These microcontrollers can measure the resistance and convert that number to a temperature reading. Both non-programmable and programmable digital thermostats are set manually to a single temperature set point the same as electromechanical thermostats. Programmable digital thermostats offer additional features that allow for temperature setback at predetermined days and times that correspond with heating and cooling need making programmable digital thermostats more energy efficient.

Sensors

In commercial buildings, wall-mounted sensors are thermostats that are installed to control building temperature where tamper-proof controls are required, such as public access areas of buildings, and to maintain a constant temperature set point. Wall-mounted sensors are typically installed in a locking case requiring a manufacturer-specific key to gain access.

There are several different switch types used in wall-mounted sensors that include mercury, non-mercury and electronic. Mechanical sensors that utilize preset, adjustable single or multistage hermetically sealed snap-in mercury switches offer precise temperature control that is generally unaffected by fatigue and vibration and will operate in any position without leveling. Preset sensors are purchased at a single standard temperature set point that cannot be adjusted. Adjustable sensors (both single and multistage) have set points that can typically be adjusted from $+40^{o}$F to $+90^{o}$F. Non-mercury mechanical sensors typically use preset bimetal switches. Electronic sensors that are digitally controlled by centralized building systems are less commonly used, especially in smaller facilities.

Since the objective of this study was to locate those sensors that are associated with building heating and cooling systems that are readily accessible such as wall-mounted sensors, capillary sensors in the heating and cooling ductwork of a building that control building temperature or installed in a refrigeration unit to control equipment temperature are examples of temperature sensors that are not readily accessible and were not included in this study.

Thermostat and Sensor Types

Research information compiled on thermostats and sensors currently being sold and installed that contain mercury are shown in Table 1. Data and information for older temperature control technologies (prior to 1953) was not readily available and is not included in Table 1.

Table 1. Thermostats and Sensors Currently Manufactured and Installed

Thermostat/Sensor Type	Switch Type	Contains Mercury?
Sensor	Mechanical	Yes
Sensor	Electronic	No
Thermostat - Mechanical	Bi-metal Snap Action	No
Thermostat - Mechanical	Bi-metal Mercury Switch	Yes
Thermostat - Line Voltage – 120/ 240V	Direct Voltage	No
Thermostat -Line Voltage – Low Voltage 24 V	Direct Voltage	Yes
Thermostat - Digital	Electronic	No

Many product descriptions from the manufacturer did not indicate the type of switch used or if a mercury ampoule was present[2]. For this reason it was often necessary to review the product specification sheet diagram to confirm whether a specific thermostat contained mercury or remove the outer cover and look for the mercury ampoule(s) though direct observation to determine if a mechanical thermostat or sensor contained mercury.

Thermostat Manufacturers

There are many manufacturers of thermostats and sensors for building temperature controls. Honeywell was the most common manufacturer found during study development for both mercury and non-mercury thermostats. Several manufactures print the contractor or third-party distributor name on the thermostat they manufacture. For the purposes of this study and based on available information, the manufacturer rather than the contractor or third-party distributor name was documented during study development and data collection.

[2] Some mechanical thermostats and sensors have the same outer cover and contain either a mercury switch or a non-mercury snap action switch.

STUDY DEVELOPMENT

Goals and Objectives

The goal of the Mercury Thermostat Research Study was to develop a method to reliably estimate of the number of mercury-containing thermostats for commercial buildings in King County. Results of the study would enable King County to better estimate how many mercury-containing thermostats are currently in use and how many are potentially disposed annually.

Estimates of the number of mercury-containing thermostats in commercial buildings in King County was determined by collecting statistically-significant survey data from randomly selected sample sites for multiple building variables and by utilizing available commercial building data. A predictive mathematical model to derive statistically-reliable estimates was used for data analysis.

The study was designed to provide data and information on:

1) How many mercury thermostats are in King County commercial buildings?
2) What is the building variables associated with thermostat use?
3) Is King County Assessors Office (KCAO) commercial building data a reliable source for statistically-significant data analysis for this study?

Method Development

Library research, elective site investigations and manufacturer and trade information were used by the research lead to obtain information during study development. The study design was evaluated for feasibility of meeting study objectives. Key study design elements to define the sampling method, data collection and analysis were:

- Define study population
- Locate reliable population data source
- Determine statistically-significant sample size
- Construct data collection instrument that is unbiased and maintains respondent's interest with minimal inconvenience
- Develop data coding system to facilitate efficient and consistent data entry
- Develop relational database to enter, organize and evaluate data collected
- Utilize multivariate statistical techniques for quantitative analysis using SPSS statistical analysis software.

During method development, it was recognized there are many switching devices which contain mercury that are used within a building for purposes other than controlling building temperature. Pressure, level and temperature switches that are used for equipment controls are a few examples.

For the purposes of this study, research was focused on the types and applications of mercury and non-mercury thermostat switching devices used to control building temperature that are installed and replaced as a normal course of new construction and building remodeling/renovation. Research for this study was limited to single and multistage thermostat technology with on/off control technology that includes differential, cycle rate and anticipator controls commonly used for heating/cooling commercial buildings. These thermostats are thought to have a high potential for disposal to the landfill and resulting mercury release.

Limited data was collected for wall-mounted temperature sensors due to difficulties in identifying mercury content. Sensors are typically housed in a tamper-proof cover, frequently without manufacture identification. Without visual identification of a snap-in mercury switch or readily available manufacture data, for the purposes of this study, sensor data will have limit data quality.

Initial Research and Investigation

An informational investigation of the King County Environmental Laboratory in Seattle Washington was conducted by the research lead during study development. The multi-use building represented both occupant and non-occupant use space with the majority of the space dedicated to special use. Temperature was controlled by a pneumatic system with no mercury thermostats observed. Additionally, windows that open to allow ventilation from outside air were present in occupant spaces.

Although this site investigation did not prove to be representative of a standard commercial building, the general information obtained on heating and cooling systems proved very valuable. Two key pieces of information were obtained from the site contact on heating and cooling system configuration and maintenance. 1) Most systems tend to be a hybrid of the original system installed. Over time technicians can repair, replace and upgrade systems using their own judgment on the best course of action to meet the needs of the building that do not necessarily match the manufacturer's original design; and, 2) the prescribed heating and cooling schematic in the original building design can be altered by the installation contractor if it meets the same building load, for example, if digital thermostats are prescribed mercury thermostats can be installed by the contractor if they meet the same temperature control specifications.

A second informational investigation of the Fred Hutchinson Research Center in Seattle Washington was conducted by the research lead during study development. This multi-building campus was particularly helpful during initial research because it represented what was believed to be a good cross section of building age, use and varying stages of building renovation all within the same location.

Site investigations were conducted at the Fred Hutchinson Research Center in several older structures built in 1930 to 1940 that were approximately 10,000 to 15,000 square feet. Many of the areas within each building had been renovated and contained primarily non-mercury thermostats. However, several mercury thermostats were located in unoccupied areas of the building that were believed to be building artifacts and, to a lesser degree, occupied areas where the thermostats had not been replaced during renovation or were original to the building where no renovation had occurred. Special use areas of buildings such as the freezer repository and document storage warehouse were also investigated and were found to have mercury thermostats associated with ceiling-mounted electrical heaters designed for climate control of non-occupant spaces.

In contrast, new buildings at the site were built starting in the year 2000 and contain state-of-the-art digitally-controlled heating and cooling systems. All heating and cooling needs are controlled through the use of digital building sensors that send digital signals back to the main unit for each specific zone within the building. No mercury-containing thermostats or sensors were observed in buildings built in or after 2000.

Reconnaissance Study

Based on initial research and informational investigations, a draft data collection instrument was developed by the Research Lead to test probable data collection variables. The instrument was pre-tested with several area businesses and was modified according to feedback received to further clarify project objectives. Data collection variables include:

- Heating/cooling system;
- Building characteristics such as ceiling height, age and square feet;
- Predominant use of space (e.g. retail, office, etc.);
- Number of mercury and non-mercury thermostats.

Using the modified data collection instrument, a reconnaissance study was conducted by the research lead to further test data collection variables and study feasibility. Each of 35 businesses selected was easily accessible by public access for observational purposes with a varying range in year built, square feet and building use. For each geographic location, the random selection process of choosing every third building was used to assure building variability and reduce bias. The types of buildings included in the reconnaissance study were:

- Small to medium retail spaces
- Large warehouse retail spaces
- Public library
- Bank
- Grocery stores
- Mini-marts
- Greenhouse

Specific building information, such as square feet, age of building and predominant use was obtained from the KCAO commercial buildings database after the reconnaissance data was collected. Based on reconnaissance and KCAO data for a specified geographic location, the following was observed:

- All mercury thermostats observed during the reconnaissance study were in buildings built between 1972 and 1978 with average square feet of 2,780 (min 800 and max 9,348 square feet).
- Digital thermostats were observed in buildings built in 1982 to 1997 with average square feet of 5,000 (min 4,000 and max 6,000 square feet).
- The largest buildings observed did not have visible thermostats in the majority of the space accessed by the general public. These buildings were built between 1982 and 1997 and have average square feet of 61,936 (min 3,500 and max 142,158 square feet).
- A correlation between building use, square feet and year built and/or remodeled and the likelihood that the building contained a mechanical thermostat containing mercury was observed.
- Although age of building appears to be a likely indicator where the majority of mercury thermostats are found, buildings that are remodeled can still contain mercury thermostats even though digital technology was available at the time of the renovation.
- Buildings observed did not always contain one type of thermostat. A combination of mercury and non-mercury thermostats were observed for some buildings built between 1972 and 1978.

Buildings with the common factor of square feet had as high a degree of variability for the types of thermostat(s) in use as those that did not share this same common factor. The following figure illustrates the great differences between three hypothetical 5,000 square foot commercial buildings based on building variables and percent use.

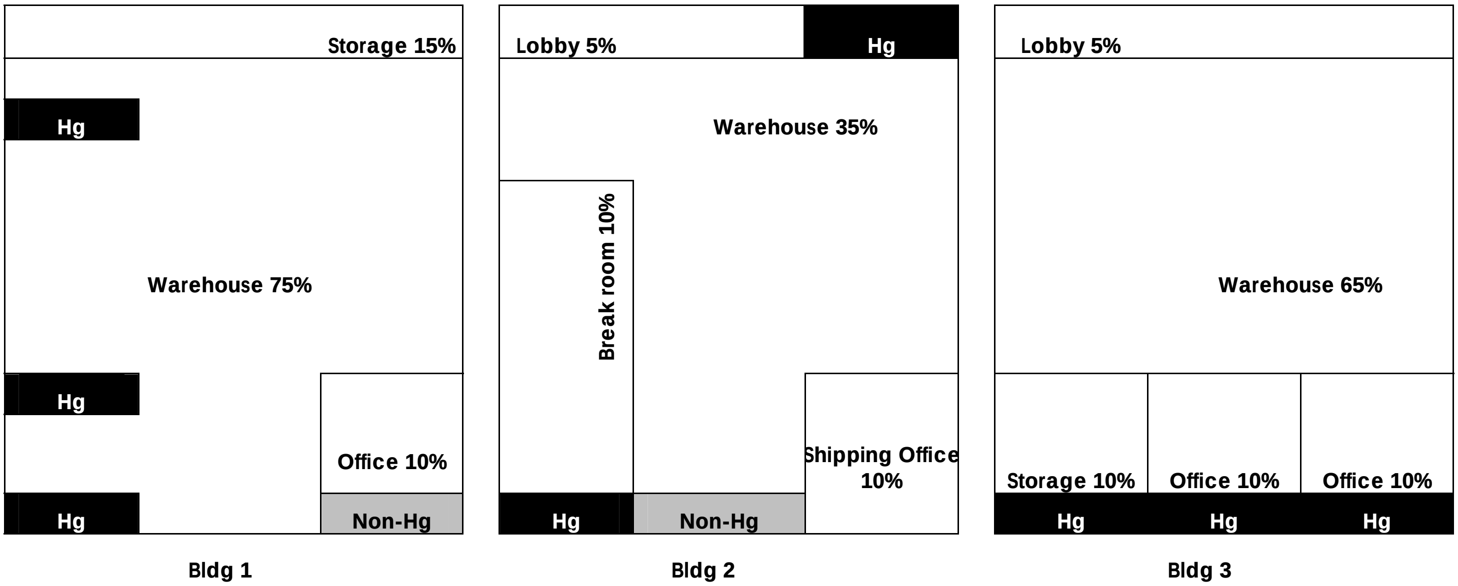

Figure 2. Building Variability Based on Percent Use - Hypothetical Example

Using the example in Figure 2, it's clear that simply counting thermostats in each building would not be sufficient to extrapolate to all King County commercial buildings. Using the variable of square feet in combination with how many thermostats were found would also not adequately predict the number of thermostats in all buildings.

Data from Figure 2 are presented in Table 2 which shows the associated Local Area Characteristics variable for each building and the associated thermostat type. Although this example is hypothetical and does not represent specific sample sites, it is representative of the variability of all sample sites surveyed during the reconnaissance survey.

Table 2. Local Area Characteristics – Building Variables; Hypothetical Example

			Ceiling Height Type			Number / Type of Thermostat			
Sample Site	**%Use**	**Use Type**	**Warehouse**	**High**	**Standard**	**Hg**	**Non-Hg**	**No Heat**	**Heat Type[3]**
Bldg 1	75%	Warehouse	X			3			CMH
	15%	Storage			X			X	N/A
	10%	Office			X		1		EBB
Bldg 2	35%	Warehouse	X				1		EBB
	10%	Break Room			X	1			FA
	10%	Shipping Office			X			X	N/A
	5%	Lobby		X		1			FA
Bldg 3	65%	Warehouse	X					X	N/A
	10%	Office			X	1			FA
	10%	Office			X	1			FA
	5%	Lobby		X				X	N/A
	10%	Storage	X	X		1			CMH

Ceiling height, heat type and use of the space appeared to be variables with greater predictive value for thermostat type and application. In order to extrapolate the sample data to all commercial buildings in King County, thermostat data and these predictive variables were documented and used to formulate the Sampling and Analysis Plan for this study.

[3] Where CMH = Ceiling Mounted Heater; EBB = Electric Baseboard Heater; FA = Forced Air Heat; N/A = not applicable – no heat

Hypotheses

Based on initial research data, factors that contributed in the development of the following hypotheses were the age of buildings that are likely to contain a mercury thermostat based on the year technology for both the mercury and digital thermostats were introduced and installed, the conditions where a thermostat would be replaced and what type of an environment where mercury thermostats are likely to still be in use.

- There is a direct correlation between the year built and/or remodeled and the likelihood that the building contains a mechanical thermostat containing mercury.
- The age range of a building most likely to contain wall-mounted mercury thermostats is 1953 – 1980.
- Mechanical thermostats containing mercury are used in conjunction with specific heating and cooling equipment that are based on building requirements.
- Buildings that are remodeled can contain mercury thermostats even though digital technology is available. Cost of replacing thermostats that are working properly can preclude thermostat replacement with a digital thermostat.
- Buildings designed for heavy industrial use such as manufacturing are more likely to contain mercury thermostats since they are more durable and less sensitive to vibration and air particles associated with industrial buildings.

King County Assessors Office Database

In addition to initial research and reconnaissance data, existing electronic data was used to formulate the Sampling and Analysis Plan for this study. The best available source of electronic data for commercial buildings specific to King County is from the King County Assessors Office (KCAO). The KCAO database provided data from the Assessors site assessment record from periodic site visits as well as self-reported changes to the recorded information from the commercial building owner. There is one record for each commercial building with no upper limit on the number of buildings per parcel. For the purposes of this study, the data contained in the KCAO database is assumed to be the most accurate record available of the number and specific characteristics of commercial buildings in King County.

The following data fields are available in the King County Assessor's Commercial Building Database. Highlighted fields show those selected as containing information that was used for this study. KCAO intended interpretation of each data field was confirmed through the Assessor's office and is reflected in Table 3 (Roe, 2005). Commercial Building Record Description.

Table 3. KCAO Commercial Properties Database Fields.

Field Name	Description
Major[4]	Parcel number associated with each property
Minor[5]	Plat number unique to parcel number
Building Number[6]	Building number within parcel
Number of Buildings	The number of buildings aggregated into this record.
Address	Location of parcel/plat
Number Stories	Number of stories for specific building number
Predominant Use	Use listed for specific building on property
Shape	Standard shape description
Construction Class	Building classification by construction type
Building Quality	Overall soundness of building
Building Description	Type of building (i.e. warehouse, office etc.)
Building Gross Square Feet	Square feet that includes all spaces
Building Net Square Feet	Square feet that includes only occupant space
Year Built	Year building was initially constructed
Effective Year	Year building was last remodeled
Percent Complete	Building construction or remodeling completed
Heating System	Type of heating system based on twenty pre-selected heating types
Sprinklers	Presence/absence of sprinkler system
Elevators	Presence/absence of elevator in building

The 2004 KCAO Commercial Building database used for study development and sample selection contained records for 40,949 commercial properties. Included in the commercial building database are commercial residential properties, such as apartment buildings. Since a prior phone survey for residential buildings had been conducted to determine the number and type of thermostats in households (LHWMP et al, 2004), residential properties were excluded from this study. The following residential Predominant Use Codes were removed (Table 4):

[4] Primary unique KCAO identifier for each record
[5] Secondary unique KCAO identifier for each record
[6] Used to further identify specific sample site

Table 4. KCAO Predominant Use Codes Removed

Predominant Use Code	Description
300	Apartment
330	Home for the Elderly
352	Multiple Residence (low rise)

When residential buildings are removed from the dataset, the remaining number of commercial buildings for all other predominant uses is 30,684. Appendix D provides data on the distribution of all other KCAO Predominant Use Codes that were included in the study.

Random Sample Selection

Systematic Sampling Strategy

For the purposes of statistical analysis and data extrapolation, a systematic sampling strategy was developed. Using the KCAO Commercial Buildings Database, distribution of the sample set by year built or remodeled was chosen based on the availability of the first mercury thermostat and first digital thermostats sold and installed. The proportionally-based and heavy industrial subset random sample selection was based on the following criteria:

Proportional Sample 1 (P1) - Buildings built or remodeled prior to 1953: The type of mechanical thermostats installed and used in 1900-1952 was not readily available. Difficulties in obtaining data during study development include variable historical technology and insufficient documentation readily available for review. Since this dataset contain buildings built or remodeled prior to the manufacture of mercury thermostats, for the purposes of this study, it is assumed that thermostats within this time period do not contain mercury or are no longer in use.

Proportional Sample 2 (P2) – Buildings built or remodeled between 1953-1980: In 1953, Honeywell Corporation (one of the largest manufacturers and distributors of thermostats) manufactured and sold the first Honeywell T86 round thermostat. This particular mercury-containing thermostat is very popular and is still sold and in use today. Many companies followed Honeywell and the manufacture of mercury thermostats was common during this time. The assumption for the years 1953-1980 is the majority of thermostats installed during this time period will contain mercury and are still in use.

Proportional Sample 3 (P3) – Buildings built or remodeled after 1980: In 1981 the first digital thermostat was manufactured and sold. Not all conditions are appropriate for the use of digital thermostats. It is assumed that during 1981-2004 some mercury thermostats may have been replaced by digital thermostats. It is also assumed that digital thermostats were more frequently installed instead of mechanical thermostats containing mercury for new construction. During this time period a combination of both mechanical (mercury-containing) and digital thermostats are in use.

Sample selection for the proportionally-based sample selection was based on the percent of the total sample set as illustrated in Table 5.

Table 5. Proportionally-Based Random Sample Selection Based on Year Built.

Proportional Sample Designation	Year Built or Remodeled	KCAO Commercial Properties n=	Total Properties %
P1	1900-1952	1,936	6
P2	1953-1980	15,316	50
P3	1981-2004	13,390	44

Heavy Industrial Sample (H): A stratified sample subgroup was also included for the 42 heavy industrial sites in King County. These 42 sites were considered anomalous to the overall dataset. Heavy manufacturing and industrial processes were thought to require heating and cooling conditions not seen in commercial buildings designed for other than heavy manufacturing use.

Data Composition and Unique Identifiers

Random sample sites were generated from the KCAO data using Major, Minor, and Building Number fields as KCAO unique identifiers. Data were arranged according to proportional and subset distribution and were assigned a unique sample site identifier (Site ID). Based on data distribution, random numbers were generated by Site ID using Microsoft Excel. All sample sites had an equal opportunity to be selected within each dataset.

For KCAO database verification and to ensure all potential commercial buildings were represented in the random sample, parcel descriptions were included where no building was indicated (lots, garages, etc.) and for buildings that were listed as having no heat.

Percent Sample Selection

A 1.0 percent random sample was drawn (excluding heavy industrial subset data) from the 2004 King County Assessor’s Office commercial building database proportionally for each of the three time periods based on the expected number of sample sites (300 sample sites). To assure sufficient randomly-selected sites were available in case of site refusals, a slightly larger sample was drawn proportionally for a total of 400 sample sites.

A separate random sample was drawn from the 2004 King County Assessor’s Office commercial building database for the heavy industrial subset population, predominant use code 495.   Seventeen samples, 40 percent, of the data set were drawn randomly with 5 additional samples drawn for a total of 22 sample sites to assure sufficient randomly-selected sites were available as alternative sample sites for site refusals.

Acceptable Statistical Accuracy

The proportional sample was drawn with an acceptable statistical accuracy at the 95 percent confidence level at a 5 percent level of error $\pm$ 1 percent. Sample sites drawn for the more anomalous heavy industrial sample subset were not held to the same statistical accuracy. With limited researcher availability and the larger scope of the proportional sample set, for the heavy industrial subset samples were drawn with an acceptable statistical accuracy at the 95 percent confidence level at a 20 percent level of error. Consultation with the project statistician confirmed these levels were acceptable to meet project objectives.

Sample Distribution Bias

Sample sites were assigned to each field researcher to assure that any bias in sample distribution was within acceptable limits. An independent review of the random sample distribution was provided by the project statistician. The Predominant Use building category in the KCAO database was evaluated for the effectiveness of the random sample drawn for the study. Although a random sample does not guarantee that all categories in a sample will be reproduced exactly, it does guarantee that each category has the same chance of appearing in the sample as in the population studied. Based on these evaluation criteria, the random sample drawn for the study survey was noted by the project statistician as “remarkably good in its reproduction of the KCAO database” and is a “statistically efficient sample”.

Bias in sample distribution was evaluated by verification index for each field researcher. A statistical evaluation of the distribution of sample sites was completed by the research lead using KCAO data by Year Built, Square Feet and Predominant Use (see summary data calculations in Appendix G).

Comparable Index= Year Built Index * Ln Square Feet Index * Predominant Use Index

Figure 3. Bias Verification Index Equation

Where Comparable Index is the total numerical value for each site, Year Built Index (KCAO Year Built * 0.01), Ln Square Feet Index (Log normal * KCAO Square Feet) and Predominant Use (KCAO Predominant Use *0.1) assign numerical values that calculate an indexed rating for each sample site to compare researcher site assignments based on the variables for age of building, square feet and predominant use.

The comparable median index by field researcher indicates no bias was introduced based on building variables assuring that no one researcher received any one building type and that all building types were equitably distributed. An independent review of the results provided to the project statistician verified no bias in sample distribution.

Table 6. Sample Distribution Bias Verification Index

Researcher	n =	MIN	MEDIAN[7]	MAX
A	83	3,993.38	6,295.16	19,725.72
B	84	4,431.93	6,060.71	9,902.88
C	91	4,352.79	7,014.21	14,569.95
D	72	4,297.29	7,648.89	16,551.36
E	48	4,105.34	6,269.75	17,477.72
F	32	4,126.77	6,108.86	8,964.13

Sample Site Definition

For the purposes of this study, a sample site is defined as a single building, regardless of the size, use, occupancy or number of businesses it contains, whose structural footprint is continuous. Structures that reside on the same parcel/plat but are not attached are considered a separate building and not considered part of the sample site.

Variations such as a very large 300,000 square foot building, a multiple floor high rise to a 100 square foot pump house and a 1,000 square foot retail store could all be selected in the random sample. All space within a single building regardless of the number of addresses or businesses (occupants) of that building was considered a single sample site.

[7] Results demonstrate no analytical bias due to random sample generation, sample selection and sample site distribution to field researchers.

Data Collection Variables

The data collected for this study was assumed to be highly variable. Examples of sample site variability include a multitude of heating and cooling systems, their associated thermostat controls, use of building, square feet and age of building. To collect reliable data that could be used for statistically-significant data extrapolation, the data collection variables selected provide information and data on the:

- Accuracy and reliability of the database used and data obtained for sample site.
- Potential parameter selection for data extrapolation.
- Mercury thermostat use and occurrences in King County.

Data Limitations

The following limitations may affect the accuracy of data collected and analyzed.

King County Assessors Office Data

- Electronic data provided by the King County Assessor's Office may have limited reliability representing all buildings currently in King County.
- KCAO database may not represent current building conditions. Visual verification by an assessor occurs in 2-5 year intervals with inspections randomly selected.
- Data is updated based on information called into the Assessor's Office based on property owner's call-in information of errors in their property information. Information is not visually confirmed by an inspector;
- Not all parcel/plat numbers contain buildings so the total count of possible commercial buildings in King County is less than 30,642;
- Buildings within a specific predominant use type do not have a set number of thermostats based on any other comparable data (e.g. thermostats per square foot, thermostats per heating/cooling type, etc.);
- The type of heating source is not known for 1,455 commercial buildings and is listed as unknown or none;
- Multiple heating and cooling systems may be present at a building but not recorded in the Assessor's database since only one code is used for each parcel/plat number
- Building age based on KCAO year remodeled does not necessarily mean a thermostat has been replaced or installed. Category represents all building/property remodel activities.
- Multiple parcel/plat numbers represent a single building.

Data Collection

- Building characteristics have a high degree of variability. Within the same category of buildings, such as a warehouse, varying ceiling heights, number of stories, square footage and predominant use (e.g. manufacturing vs. retail) can be vastly different making data collection difficult for some buildings.

- Not all areas of a building are remodeled at one time. Some older thermostats may still be in use even though a building has been remodeled after 1980.
- Information obtained during the field study may potentially have limited accuracy based on the extent of knowledge, availability and interest of the site contact.
- Unoccupied building space may contain mercury thermostats that are not accounted for.
- Depending on who is responsible for handling hazardous materials at the site, accurate records may not be available for how many thermostats are in the building at present time for those buildings that are remodeled.
- Building Engineer and/or contractor maintains information off-site;
- Sensitive areas of building not accessible;
- Building size and site contact availability prohibits the time needed to accurately count each thermostat present.

Model Limitation

- Statistical models developed for this study are based on individual KCAO commercial building datasets for years 2004 (survey study) and 2005 (data extrapolation) and may not be effective for other data applications.
- Models may have limited predictive value for future extrapolations of KCAO commercial building data. Unknown variables such as continual changes in exiting buildings (e.g. remodel, demolition, changes in building use, etc.) and the growth of new construction in King County may change how the Assessor's Office track and document commercial buildings in the future.

FIELD DATA COLLECTION METHODS

Researcher Recruitment and Training

Study data was collected by experienced field researchers to assure accurate data for each sample site. The Local Hazardous Waste Management Program in King County provided several Health and Environmental Investigators and necessary equipment such as vehicles, computers, digital cameras and mercury spill kits from its Public Health—Seattle & King County and Water & Land Resources Division offices for the duration of the project.

Field researcher training was provided by the research lead to assure consistent and accurate data collection. Both in-class and one-on-one in-field trainings were provided. Training goals were to provide data and information that would allow the field researchers to become proficient with the data collection instrument, be able to visually identify and document the many types of heating/cooling systems, mercury and non-mercury thermostats and building characteristics.

Single Blind Data Collection

A single blind data collection method was utilized to assure data quality and reduce the potential of personal bias. Field researchers were not provided information regarding the assumptions or hypotheses developed for the study prior to or during the data collection event. Each field researcher was assigned an anonymous Researcher ID (letters A-F) that was known only to the individual field researcher and research lead for site assignment, tracking and report generation purposes. Individual site surveys, project tracking and data quality were data-focused and did not include field researcher bias.

Data Collection Instrument

The data collection instrument (Appendix A) was developed to facilitate consistent data collection by all field researchers reducing the potential for bias and error. The variables selected for data collection were identified as those variables most likely to be associated with the occurrence of mercury thermostats and associated building characteristics. Data variables were also selected for verification of the KCAO Commercial Building Database as a reliable data source for data analysis and extrapolation. Components of the data collection instrument are:

- Site Contact Data
- Sample Site Visit Quality
- KCAO Database Verification
- Local Area Characteristics

Data was not coded at the time of data collection. All data compression and coding was done by the research lead at the time of data entry. Regardless of the complexity of the sample site, if a building had multiple addresses, businesses or site contacts each sample site was documented on an individual data collection instrument. Data was collected for all space within a single building, such as office, warehouse, storage, repair shop, loading dock, etc.

Site Contact Data

The quality of data collected relied heavily on the reliability of the information received from the site contact based on their knowledge of the building structure, heating cooling systems installed and the associated thermostats for their site. To track and evaluate data integrity, field researchers completed the contact information portion of the data collection instrument (see Appendix A). Data received was coded during data entry by the research lead using predetermined data fields to categorize the quality of information based on job category (see Table 7).

Table 7. Data Integrity Verification by Site Contact Job Category

Site Contact Job Category
Building Custodian
Building Engineer
Business Administrator/Manager
Business Front Office/Retail Clerk
Business Owner
Employee NOS
Facilities Manager
HVAC Contractor
Maintenance Engineer
None given
Other
Property Manager
Property Owner
Section Manager/Supervisor

Sample Site Visit Quality

The quality of data collected at each sample site was evaluated by a predetermined ranking system for visit quality. Only those samples sites with a visit quality of 1 or 2 were considered acceptable and complete. To achieve statistically-significant data, a total of 300 *completed* sample sites for the proportional population and a total of 15 *completed* sample sites for the heavy manufacturing subset population were needed to meet the criteria for visit quality 1 and/or 2. Even though a site has been surveyed, poor visit quality that does not meet the minimum visit quality 1 and/or 2 may require an additional site be added from the list of randomly selected sites to the total sites surveyed to maintain the total count of useable data collected. Visit quality and completeness was documented by the field researcher on the data collection instrument in the visit quality section.

Visit Quality 1 - Useable Data.

A site survey with all of the following characteristics would be indicated on the data collection instrument as a visit quality 1:

1) Access to the site was sufficient to identify and document the type and number of thermostats. If the building did not contain thermostats, it was documented and still considered a completed site survey.
2) Access to the site was sufficient to identify and document the type of heating and cooling system(s); and
3) Building use was identified and documented.

It was important that all areas of the building were visually observed and documented. A site survey did not qualify for a Visit Quality 1 based on a phone interview. For special circumstances where a building was too large to observe all thermostats and building variables, such as a 37-story high rise, an acceptable method to obtain a visit quality 1 rating would be to

1) Observe and document sufficient information during the initial site survey to determine heating/cooling system, building variables and the number and type of thermostats. This can be done through reviewing a recent building schematic and confirming 10% of the building's thermostats, heating/cooling system(s) and building variables through direct observation.
2) Follow-up by phone with site contact, when needed, to further interpret building schematic to complete site survey.

Visit Quality 2 - Useable Data

Useable site survey data collected that did not meet all visit quality 1 criteria would have the following characteristics:

1) Access to the site was sufficient to identify the type of thermostats for the building but was not sufficient to count all thermostats;
2) Access to the site was sufficient to identify the type of heating and cooling systems at that site; and
3) Building use was identified.

A completed sample site using the above criteria would be indicated on the data collection instrument as a visit quality 2.

Visit Quality 3 - Unusable Data (Limited Access).

Access to a site that was insufficient to determine the type and number of thermostats, heating/cooling system(s) and building use was considered an incomplete site survey and would be indicated on the data collection instrument as a visit quality 3. A replacement sample site was given to the Field Research from the list of randomly selected sites.

Visit Quality 4 - Unusable Data (Site Refusal)

If a site refused entry or required information, the field researcher documented the site survey on the data collection instrument as a visit quality 4 and went to the next assigned sample site. A replacement site was issued from the random samples selected for each site refusal to maintain the minimum number of completed sample sites needed.

Visit Quality 4 - Unusable Data (Non-Building Site)

If a site did not contain a building, the field researcher documented the site survey on the data collection instrument as a visit quality 4 and went to the next assigned sample site. A replacement site was issued from the random samples selected for each non-building site to maintain the minimum number of completed sample sites needed.

Visit Quality 4 - Unusable Data (Site Not Located)

If a site could not be located, the field researcher documented the site survey on the data collection instrument as a visit quality 4 and went to the next assigned sample site. A replacement site was issued from the random samples selected for each site not located to maintain the minimum number of completed sample sites needed.

King County Assessors Office Database Verification

Data was collected for Year Built, Year Remodeled, Predominant Use, Building Description and Square Feet. KCAO database data was provided on the data collection instrument for these variables for each sample site. A visual verification was made by the field researcher during the site survey to confirm whether the data provided is the same as what was observed on site. A check box was provided on the data collection instrument to document verification.

Local Area Characteristics Assessment

The purpose of the Local Area Characteristics Assessment was to describe each unique space within a building by:

- The purpose of the space
- Heating/cooling unit
- Ceiling height
- Percent of the building it pertained to
- The thermostats that were observed.

For example, 50 percent of a building could contain 3 electric baseboard heaters with standard ceiling height and 2 non-mercury thermostats in a space designated as an office. In the same building, 50 percent of the building could contain 6 ceiling-mounted gas heaters, all with mercury thermostats with a warehouse height ceiling designated for document storage. Using this example, 2 Local Area Characteristics Assessments would be completed for this site.

Building Artifacts

Many sample sites have been remodeled or partially remodeled with old heating/cooling systems and thermostats that are no longer in use and have not been removed. To document these systems and thermostats, the Local Area Characteristics Assessment data field provided a check box to record the status of artifact.

Locating Sample Sites

All samples sites are located within the cities and unincorporated areas of King County. The site address listed in the KCAO commercial building database was used to document the site location on each data collection instrument. For those sites where address information was incomplete, other resources such as the King County iMAP/Parcel Viewer Database and Thomas Guide maps were used to document site location.

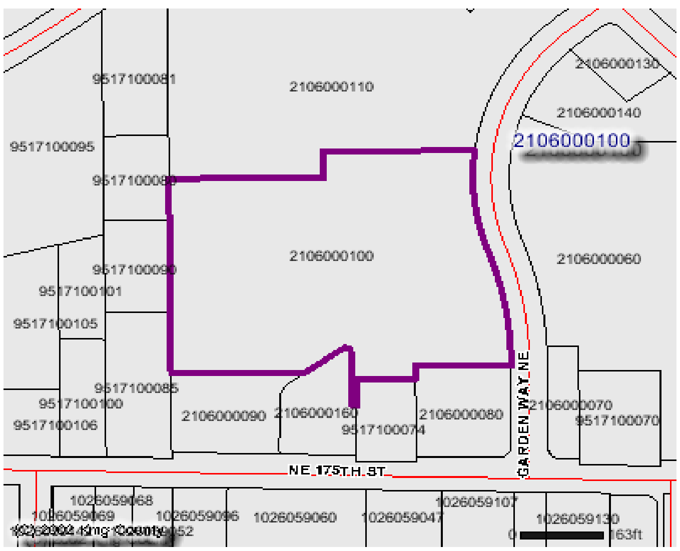

Figure 4. King County iMAP/Parcel Viewer Map

Using the KCAO database major/minor (parcel/plat) unique identifier and the King County iMAP/Parcel Viewer database, field researchers were provided a site map containing the parcel/plat number and the surrounding street information. The site map was attached to each data collection instrument for each sample site.

In addition to the King County Parcel Viewer map provided, other tools were used by the field researchers to locate sample sites, such as website search engines such as www.switchboard.com. or Thomas Guide map book. Since this was a blind study, no additional information from the King County Assessor's Office or King County iMAP/Parcel Viewer databases were used by the field researchers to locate information beyond site location.

Non-building sites

Within each stratified population, each commercial building listed in the KCAO database had an equal chance of being randomly selected. In some instances sites were a non-building (e.g. parking lot). Since the KCAO Commercial Building Database predominantly contained properties with a building structure, field researchers conducted a site survey to verify that the KCAO database was correct and that no building had been built. If the KCAO database was correct, the site was documented as a visit quality 4 and an alternate site was issued. If the KCAO database was incorrect and the site contained a building, the field researchers completed a site survey and documented the change in KCAO building description.

Difficulty Locating Sample Sites

For the majority of sample sites, data from the KCAO Commercial Properties database correctly associated building location with a corresponding parcel/plat number and building description. However due to database complexities, incidences of variation for how a building was recorded in KCAO database were observed. These variations included:

- A single continuous building that spans over several parcel/plat numbers;
- Building addresses that did not correspond with the database
- Sites that indicated a building on site where there was a vacant lot
- Residential properties listed as commercial buildings
- Building description not current
- Commercial building was residential/commercial mixed use

For those sites where visit quality 4 was documented (e.g. no building exists, residential properties, etc.) a replacement sample site was issued.

Many sample sites contained multiple unattached buildings that did not match the description given in the database. When the exact building could not be located for sites with multiple buildings on the same parcel/plat, the field researcher used a random selection method to choose the building survey site. Random building selection consisted of an alternate pattern of choosing the building to the left, then to the right, the closest building and the building with the most remote distance. If the on site random selection method was not feasible, the research lead was contacted for assistance in random sample site selection. The alternate random building selection was documented on the data collection instrument in the comments field.

Photo Documentation

Digital photos were taken by field researchers of thermostats and sensors observed during a site survey where the presence or absence of mercury could not be determined through visual inspection. The Site ID and heating/cooling system code associated with the thermostat or sensor was documented at the time each photo was taken. Based on the review of information and photo documentation provided, the research lead provided information on the thermostat and/or sensor type and possible mercury content.

Sample Site Assignment

Each field researcher was assigned an equal balance of ten new sample sites each week. Due to the variability in building complexity, the number of sites surveyed varied each week. To meet project timelines, each field researcher's goal was to complete six sample sites a week with a visit quality of 1 and/or 2.

Random distributions of sample sites were assigned so no one field researcher would receive a single building type, complexity or complete geographical location. To reduce travel time, groups of sites were assigned on a geographical basis whenever possible. Based on completed data collection instruments received, the geographical location for each field researcher changed as groups of sample sites were completed.

Sample sites assigned and completed were tracked by the research lead for each field researcher on the Sample Status Tracking Report (Appendix B) generated from the project database. To keep field researchers informed of their sample status, individual reports were generated and distributed weekly. A weekly Sample Status Tracking Report containing data for all field researchers was also generated for use by the research lead to track:

- Overall project completion status
- Random site assignment
- Workload distribution
- Workload and progress reporting to the Project Coordinator and Management.

Quality Assurance/Qualtiy Control

A systematic data collection method was implemented through predictable and accountable variable data collection. All data collection instruments received a baseline Quality Assurance/Quality Control (QA/QC) review for completeness by the research lead. An additional 20 percent (82 data collection instruments) were randomly selected and received a full QA/QC review of all data variables by the research lead.

As a research study progresses and more information is obtained, it is not uncommon for the categorization and documentation of data collected to change as well. To effectively manage this potential, each field researcher received a periodic data review with the research lead. These follow-ups helped to assure consistent data collection for all variables across all field researchers with minimal drift in data collection interpretation.

An individual QA/QC Data Analysis Milestone Report was provided to each field researcher showing researcher's data usability (Appendix G). Data corrections were documented on the corresponding data collection instrument.

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SURVEY DATA

Data Collection

A team of six field researchers collected survey data for three months (January 4 – March 31, 2005) for 412 sample sites. From these sample sites, 346 provided useable data. The distribution of the 329 useable proportional sample data (see Table 8) show a direct correlation between the total percent of each sample type in the population and the percent useable data. Site refusals and unusable site conditions, such as mislabeled sites in the KCAO database for residential buildings, resulted in data from 66 sample sites (16 percent) as unusable.

Table 8. Proportional and Heavy Industrial Subset Data Collected

Sample Type	KCAO Commercial Buildings n=	Total Buildings in Proportional Sample %	Random Samples Surveyed n=	Useable Date Collected n=	Useable Proportional Data %
P1 = 1900 – 1952	1,936	6.0	30	22	6.7
P2 = 1953-1980	15,316	50.0	200	167	50.8
P3 = 1981- 2004	13,390	44.0	160	140	42.6
Proportional Total	**30,642**		**390**	**329**	
H = Heavy Industrial	42	N/A	22	17	N/A
Total Sample Set			**412**	**346**	

Based on the total KCAO Commercial Building population, the useable survey data collected for 346 sample sites achieved statistical accuracy goals for the project at the 95 percent confidence level for number of sample drawn as indicated in Table 9.

Table 9. Survey Data Collected at 95 Percent Confidence Level

	Project Goal %	Achieved %
Proportional Samples	5.0	5.4
Heavy Industrial Subset	20.0	18.3

Data Entry

Based on the complexity of the data collected and to assure consistent data entry, all data was entered into the project database by the research lead. This streamlined data entry method provided a process for:

- Consistent data compression and coding at time of data entry;
- Consistency of data entry across all data collected and entered;
- Consistent QA/QC and data corrections for each field Researcher.

Data Compression and Coding

Not all data required data compression and coding. Many data variables (e.g. KCAO verification data, visit quality, ceiling height, etc.) were directly entered into the project database. For those data requiring further assessment and coding, at the time of data entry, each data collection instrument was reviewed and coded according to a predetermined categorization system for each variable. Data was entered into the project database using this coding system.

During the study development phase, KCAO commercial building data indicated a possible correlation opportunity using the KCAO data field for Heat Type (see Appendices H and J) and several building variables (e.g. square feet, building age, etc.). Since KCAO Heat Type data records only the predominant system and does not reflect all systems possible within a sample site, a categorization system was developed for the study and used for data compression and coding purposes at the time of data entry (Tables 10 – 13).

Table 10. Data Compression and Coding – Heating/Cooling System Type

Heating/Cooling System Type
Individual - Cooling
Individual - H/C
Individual - Heat
Individual System - Non Specific
Inside Central System
Non-Specified
Outside Central System
Special Use - Central system
Special Use - Individual H/C
Special Use - Non Specific
Special Use - Stand alone controls

Table 11. Data Compression and Coding – Heating/Cooling Unit Location

Heating/Cooling Unit Location
Baseboard
Ceiling
Floor
Not Specified
Other
Roof
Wall

Table 12. Data Compression and Coding – Source of Energy

Source of Energy
Electric
Gas
Gas & Electric
Not Specified
Oil
Other
Waste Oil

Table 13. Data Compression and Coding – Unit Type

Type of Heating/Cooling Unit
Boiler
Forced
Furnace
HVAC
Not Specified
Pump
Radiant
Radiator
Space

KCAO data for building Predominant Use provided useful information for KCAO database verification, however like the KCAO Heat Type data, Predominant Use pertains to the whole building and does not reflect the variability within each buildings. To better captures building variability as it relates to thermostats, a categorization system was developed for the study that was used for data compression and coding purposes at the time of data entry (Table 14).

Table 14. Data Compression and Coding – Building Use

Survey Data - Building Use
Church
Day Care/Pre-School
Equipment/Special Use
Food Service
Garage
Hotel/Motel
Laboratory
Maintenance
Manufacturing
Medical Facility
Office
Other
Public Use Facility
Recreation Facility
Repair Shop
Retail
Schools
Storage Area/Shed
Transportation
Warehouse/Shipping

Data Entry Quality Assurance/Quality Control

Data entered for 412 data collection instruments resulted in 198,132 data points entered. An independent QA/QC review was conducted for 10 percent of the data collection instruments by random selection. Data interpretation, coding and entry were evaluated for 17,680 data points with an observed error rate of 0.006 percent. Results of QA/QC demonstrate no analytical bias due to data entry error.

DATA MANAGEMENT

Project Database

A project-specific relational database was developed by the research lead to capture data collected for the study. The integrity of database design received an independent review prior to data entry. Database modules were created for:

- Sample/Project Tracking
- Site Location Information
- Local Area Characteristics
- KCAO Data Verification

Sample/Project Tracking Module

Sample and project status were monitored throughout the project by the research lead using the Sample/Project Tracking module (Appendix C, Table C.1). Data maintained in this module was used to generate various reports for management, the project coordinator and field researchers to keep the project on track and on time.

Site Location Information Module

Site location information was recorded during the site survey to document the initial site visit, follow up activities, contact information and site address verification with the KCAO database. The Site Location Information module (Appendix C, Table C.2) was used to track and analyze the quality of data collected. It was important to the integrity of the data collected to indicate how the data was obtained. The quality of data received was used by the research lead as one data point in determining overall data quality for each site. By independently verifying the field researcher's self-reported visit quality rating and the quality of the data obtained based on the site contact available, data quality was assured.

Local Area Characteristics Module

Data describing the building characteristics, heating and cooling systems and the thermostats and/or sensors observed was recorded in the Local Area Characteristics Module (Appendix C, Table C.3.). This more complex core data was used to extrapolate the number of thermostats and/or sensors to all buildings in King County commercial buildings. Data was collected over a greater number of variables than utilized in the final data analysis due to uncertainties in variable attainability and statistical significance.

King County Assessors Office Data Verification Module

Verification data collected to track differences between the data indicated for each parcel in the KCAO Commercial Building Database with specific test parameters was captured in the KCAO Data Verification Module (Appendix C, Table C.4). Variables such as year built, year remodeled, predominant use, building description and square feet were used to verify the Assessor's Office data with site survey observations.

Data entered in the project database was continually tracked using a master tracking table (Appendix C, Table C.5). Sample and data variable status was monitored by the research lead to keep the project on track and within study design objectives.

MERCURY THERMOSTAT ESTIMATION

Techniques used to estimate the total number of mercury thermostats in King County commercial buildings were regression analysis and proportional attribution. Each analysis model produced separate but comparable estimates. Data used in analysis was obtained from the 30,975 commercial building assessment records (2005 KCAO Commercial Building Database) and survey data for 346 sample sites (2005 Mercury Thermostat Research Study).

Analysis of Variables

The predictive survey variables were the number of total thermostats, number of non-mercury thermostats, age of building, age of remodel, building gross square feet, ceiling height and data type (another measure of age).

Survey data collected for building use was not statistically related to other variables and not used in the estimate analysis. The KCAO variable Predominant Use describing building use contained such a large number of categories, after calculations, there would be not data left to relate KCAO Predominant Use to survey thermostat data (insufficient degree of freedom).

Data collected for the study variable, Heating/Cooling Unit, proved difficult and unreliable. This qualitative data point was subject to variable interpretation and dependent on the individual site contact's breadth and depth of knowledge of the building's heating and cooling system. Data compression and coding was difficult to interpret with certainty and accuracy and was not included in survey data submitted for analysis.

No statistically-significant relationships were found regarding thermostats in data collected at the detailed building level. Relationships were only found when aggregating data to the entire building.

Regression Analysis Model

A statistical model to estimate the total number of thermostats was developed that would find predictive statistical relationships from thermostat survey data (see Figure 5). The following regression analysis equation was found to be the best fit to the data.

$$Ln(T) = K + b1 * \text{building age} + b2* \text{remodel age} + b3 * \text{gross square feet} + e$$

Figure 5. Regression Analysis Model Equation

Where Ln(T) is the natural log of the total number of thermostats, K (1.289) is a constant (intercept) estimated by the technique, b1 (0.00585), b2 (0.00025) and b3 (0.0000148) are coefficients that calculate the contribution of the variables building age, age of remodel and gross square feet, e is unexplained variation in the regression. Taking the anti-log of Ln (T), the total number of thermostats is predicted.

To estimate the number of mercury thermostats, the number of non-mercury thermostats are subtracted from the total thermostats estimated (both mercury and non-mercury). The best predictive variables of non-mercury thermostats are total thermostats and gross square feet. To negate their correlation, a variable was created (see Figure 6) by multiplying total thermostats by gross square feet with the following equation.

$$Ln (TNHg) = b1*combine1 + e$$

Figure 6. Regression Analysis Model Variable Correlation Equation

Where Ln(TNHg) is the natural log of total non-mercury thermostats, combine1 is the product of total thermostats times the gross square feet, b1(.08747) is the coefficient that calculates the contribution of combine1 to non-mercury thermostats, e is unexplained variation in the regression. Taking the anti-log of Ln (t) – Ln (TNHg), the total number of mercury thermostats is predicted.

Both total thermostat and non-mercury thermostat regressions had difficulty with large buildings that were >200,000 square feet. Building size was limited in the regression analysis to $\leq$ 200,000 square feet. Based on survey data, buildings >200,000 square feet contained an average of 2 mercury thermostats per building. The predictive estimation was the sum of the number of mercury thermostats from regression analysis plus the number of estimated thermostats by percentage from the >200,000 square feet buildings. The regression analysis model estimated 46,941 mercury thermostats in King County commercial buildings.

Proportional Attribution Analysis Model

Retaining the regression analysis model for prediction of total thermostats including buildings up to but not including 300,000 square feet, a second technique was applied to estimate total thermostats that included building $\leq$ 300,000 square feet. In the proportional attribution model, instead of using non-mercury thermostat predictions to arrive at the number of mercury thermostats, a calculated percentage of 18 percent was applied to the total predicted number of thermostats. This calculation was derived from the survey data that indicated the average number of mercury thermostats across all building types and square feet represented 18 percent of all thermostats. The application of 2 mercury thermostats per building for buildings >300,000 square feet was also used in the proportional model. The proportional attribution method produced an estimate of 43,338 mercury thermostats in King County commercial buildings.

Generalized Extrapolation

An extrapolation of study data by non-statistical generalization provides further comparison of the analysis models. Using survey data collected from one percent of all commercial buildings in King County, data show 444 mercury thermostats. By multiplying the 444 mercury thermostats observed by 100 to extrapolate to the entire population of buildings, 44,400 mercury thermostats are predicted. This generalized extrapolation falls somewhere in between the two predictions of 46,941 and 43,338 and provides a third data extrapolation with comparable estimates.

Table 15. Comparative Estimate Analysis Models

Year Built/Remodeled Sample Type	Number of Buildings[8]	Regression Analysis Model	Proportional Attribution Analysis Model	Generalized Extrapolation
1900 – 1952 (P1)	1,796	3,145	2,912	2,600
1953 – 1980 (P2)	15,035	23,423	21,687	29,500
1981 – 2004 (P3)	14,101	18,214	16,913	10,600
Heavy Industrial (H)	43	2,159	1,826	1,700
Totals	30,975	46,941	43,338	44,400

[8] Estimates based on 2005 KCAO Commercial Properties Database.

Analytical Model Goodness of Fit

In predictive models, how well a model predicts known data is one true measure of goodness of fit. R square is a common measurement of how well the model fits the data (R-square of 1.0 perfect fit).

The R-square of 0.03 for the total thermostat regression model was not particularly good. However the model's ability to predict thermostats with a 4.2 error rate was good. The model predicted 2,314 out of the 2,433 thermostats in the sample data.

For the non-mercury thermostat model, the R-square value was particularly good at 0.98. The model's ability to predict thermostats was less accurate than the total thermostat model with a 9.6 percent error rate. The model predicted 1,800 non-mercury thermostats out of the 1990 mercury thermostats in the sample data.

Estimated Pounds of Mercury

Mercury thermostats typically contain one to four mercury ampoules, with one ampoule appearing to be the most common. In some cases, a mercury thermostat can contain 5 or 6 ampoules, however based on study observation, both five and six ampoule mercury thermostats were observed only once. Table 16 shows, for each of the analysis models, estimated pounds of mercury based on the number of mercury ampoules.

Table 16. Analysis Model Estimates for Pounds of Mercury

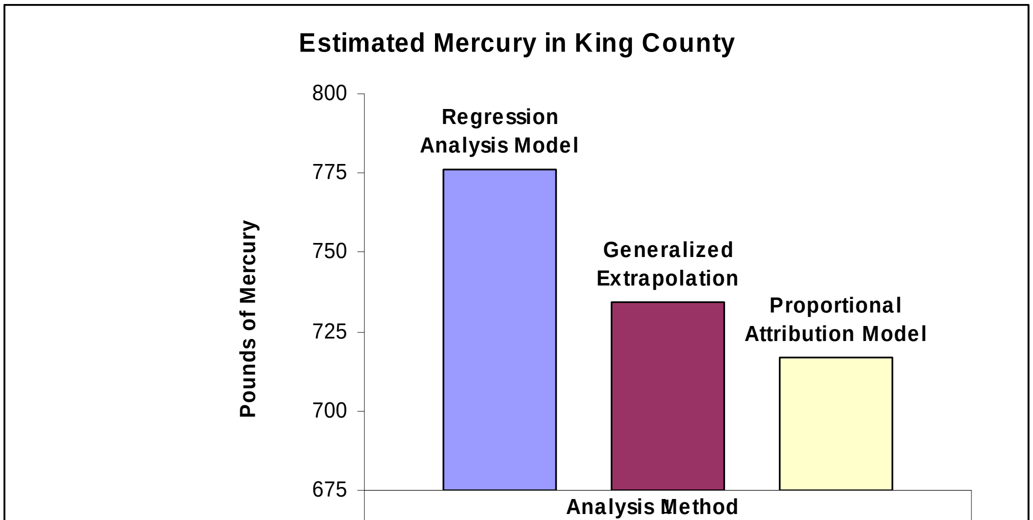
Mercury Ampoules n =	Elemental Mercury (g)	Regression Analysis Model (lbs)[9]	Proportional Attribution Model (lbs)[10]	Generalized Extrapolation (lbs)[11]
1	3	310.51	286.68	293.71
2	6	621.03	573.36	587.41
3	9	931.54	860.04	881.12
4	12	1,242.06	1,146.72	1,174.82

Data for the number of mercury ampoules for each thermostat counted by this study is unknown. The presumed amount of time needed to verify the number of ampoules in

[9] Where n = 46,941 for thermostats estimated
[10] Where n = 43,338 for thermostats estimated
[11] Where n = 44,400 for thermostats estimated

each thermostat by removing the outer cover, site contact availability and the number of samples sites precluded collecting these data.

The arithmetic mean of the commonly observed number of ampoules [12] is 2.5 per thermostat[13]. Based on this estimated number of ampoules per thermostat, the pounds of mercury in King County commercial buildings for each analysis method14 are shown in Figure 7.



	Analysis Method
Regression Analysis Model	776
Generalized Extrapolation	734
Proportional Attribution Model	717

Figure 7. Estimated Pounds of Mercury in King County Commercial Buildings

King County Assessors Office Data Verification

KCAO database accuracy was verified using study data collected for year built, year remodeled, predominant use, and square feet. For year built/year remodeled, the most recent year observed during the site survey corroborated KCAO data and was used for data verification.

Year Built: When unknown and site refusal categories are removed, study data show 94 percent agreement with KCAO data.

12 Commonly, 1 to 4 mercury ampoules.
13 Where 1 ampoule contains 3 grams of elemental mercury, 2.5 ampoules contain 7.5 grams.
14 A 3 percent difference between analysis methods.

Year Remodeled: When unknown and site refusal categories are removed, study data show 86.5 percent agreement with KCAO data.

Square Feet: When unknown and site refusal categories are removed and a 10 percent plus or minus error factor is included, study data show a 92 percent agreement with KCAO data.

Predominant Use: When unknown and site refusal categories are removed, study data show a 91.8 percent agreement with KCAO data.

Table 17. KCAO Database Usability Verification by Percent Verified for each Test Variable

KCAO Data Variable	Percent Verification from Study Data[15]
Year Built	94.0
Year Remodeled	86.5
Square Feet	92.0
Predominant Use	91.8

In the approximately 10 percent of cases where there is disagreement between study data and KCAO data it is not possible to determine which is more correct. This possible difference may be account for by simple timing where changes have occurred since the last KCAO site assessment was recorded. If consideration is taken with respect to those building types that may be susceptible to changes at a frequency that is shorter than the frequency of KCAO site assessments, evidence implies KCAO data accuracy sufficient for data extrapolation.

[15] Results demonstrate KCAO database is a viable source of data for data extrapolation to all commercial buildings in King County.

SUMMARY OF FINDINGS

Sample sites distributed by proportional and stratified data subsets were randomly selected. A total of 412 sample sites were selected. Results from 346 sample sites surveyed provided useable quality data. Both mercury and non-mercury thermostats were observed. A total of 2,433 thermostats were documented, 444 thermostats contained mercury and 1,989 were non-mercury thermostats. A total of 3,133 sensors were documented; 12 contained mercury and 3,121 were non-mercury sensors.

Thermostat data was collected through visual identification for all wall-mounted thermostats considered a permanent structure of the building. Difficulties in collecting thermostat data include identical outer casing for mechanical thermostats that contained either mercury ampoules or snap-action switches. Where possible, removal of the outer casing was necessary to positively identify switch type for these mechanical thermostats. In some instances, specialized lock boxes were installed encasing the thermostat. For the 149 mechanical thermostats documented (6 percent) that were inaccessible, data recorded for mercury or non-mercury switch type was documented as not specified. Since a statistically-significant number of sample sites did not record thermostat inaccessibility, thermostat data collected is thought to be representative.

For the purposes of this study, sensor data was collected for wall-mounted sensors and ceiling mounted heaters. Temperature sensors that reside in building ductwork or general equipment were not included in the scope of sensor data collected. Sensors were documented the same as for thermostats through visual identification. Sample site ID 18654, the largest building in the study (791,396 square feet), contained the largest number of non-mercury sensors (1,583) in a single building representing 51 percent of all non-mercury sensors documented. No other sample site contained a significant proportion of the data collected for either thermostats or sensors. For the purposes of representing thermostat and sensor total distribution, this anomalous data was excluded in the data analysis.

For large footprint buildings, accurate building schematics were used when available. Difficulties in collecting sensor data included locked sensors and ceiling-mounted heaters that were inaccessible. Data accuracy for the number of sensors documented is dependant on accessibility for visual identification of sensors and accurate building schematics for large footprint buildings. Sensor data collected for this study is under represented to an unknown degree based on data collection difficulties.

Thermostat and Sensor Distribution

A total of 2,433 thermostats were observed across all sample types for mercury and non-mercury thermostats. Distributions of thermostats show 444 (18 percent) mercury thermostats and 1,989 (82 percent) non-mercury thermostats were observed during site surveys. Data analysis of thermostat distribution by sample and thermostat type is provided in Table 18.

Table 18. Thermostat Distribution by Age of Building

Year Built/Remodeled Sample Type	Mercury Thermostats n =	Non-Mercury Thermostats n =	Total Thermostats Observed n =
1900 – 1952 (P1)	26	72	98
1953 – 1980 (P2)	295	702	997
1981 – 2004 (P3)	106	1,181	1,287
Heavy Industrial (H)	17	34	51
Total	**444**	**1,989**	**2,433**

A total of 3,133 sensors were observed across all sample types for mercury and non-mercury sensors. Distributions of sensors show 12 (0.4 percent) mercury sensors and 3,121 (99.6 percent) non-mercury sensors were observed during site surveys. Data analysis of sensor distribution by sample and sensor type is provided in Table 19.

Table 19. Sensor Distribution by Age of Building

Year Built/Remodeled Sample Type	Mercury Sensors n =	Non-Mercury Sensors n =	Total Sensors n =
1900 – 1952 (P1)	0	0	0
1953 – 1980 (P2)	3	292	295
1981 – 2004 (P3)	3	2,802	2,805
Heavy Industrial (H)	6	27	33
Total	**12**	**3,121**	**3,133**

Distribution of the 5,566 thermostats and sensors documented show non-mercury thermostats are the most observed thermostat or sensor type. Data analysis for sensor distribution indicate of the 3,121 non-mercury sensors, 1,583 (51 percent) were found at one sample site (Site ID 18654) representing a possible data anomaly. Figure 8 show adjusted data totals with anomalous data excluded.

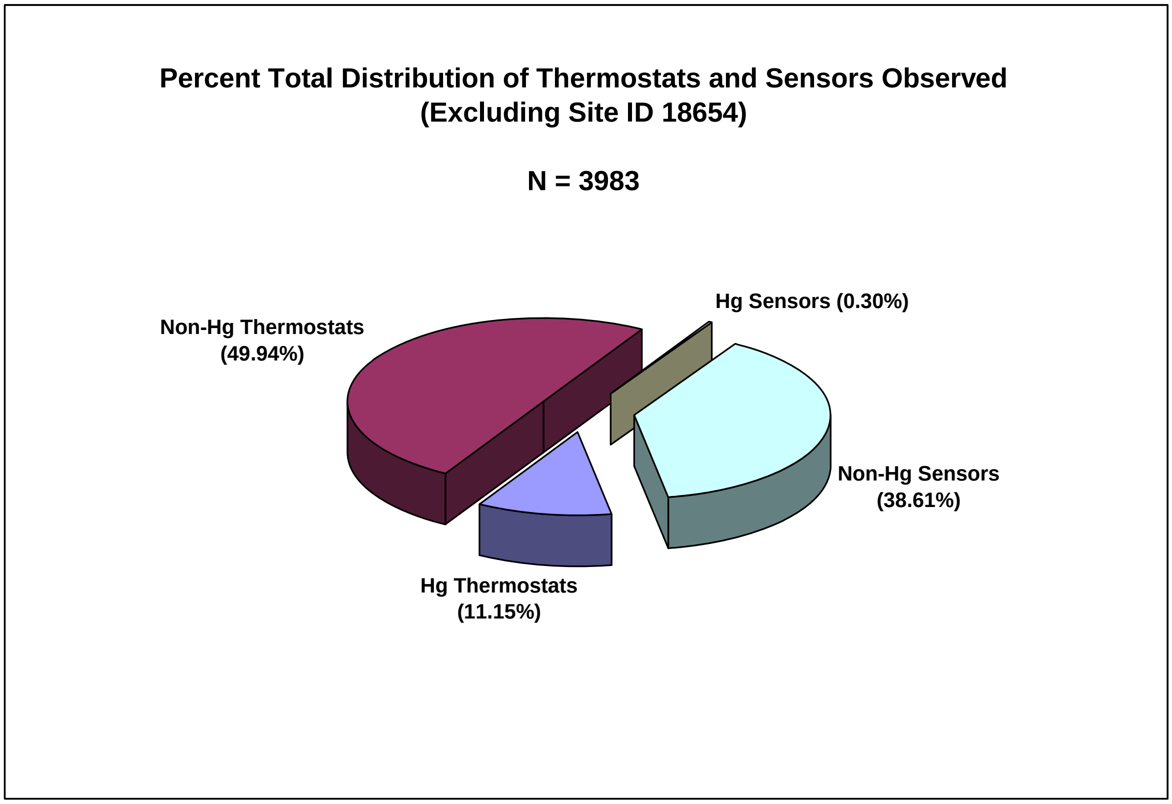


Figure 8. Total Distribution of Thermostats and Sensors Observed

Of the 346 sample sites surveyed, 294 (85 percent) of buildings contained at least one mercury or non-mercury thermostat (see Table 20 for distribution data). A small percentage of buildings (7 percent) contained only sensors and is primarily associated with large building footprint. Data also show 29 buildings (8 percent) that contained no thermostat or were not determined.

Table 20. Thermostat and Sensor Distribution by Building and Percent Total Sample

Thermostat Type	Buildings n =	Percent Total Sample %
Mercury Thermostats	134	39
Non-Mercury Thermostats	160	46
Sensors Only	23	7
No Thermostat or unknown	29	8
Total	346	

Data was collected for all thermostat and sensor types for use in comparative analysis. However, the total number of mercury thermostats in King County commercial buildings remains the key focus of data distribution for this study. In Figures 9 and 10, data show the majority of mercury thermostats were observed in the P2 proportional sample set (1953-1980) for both total and proportional sample type.

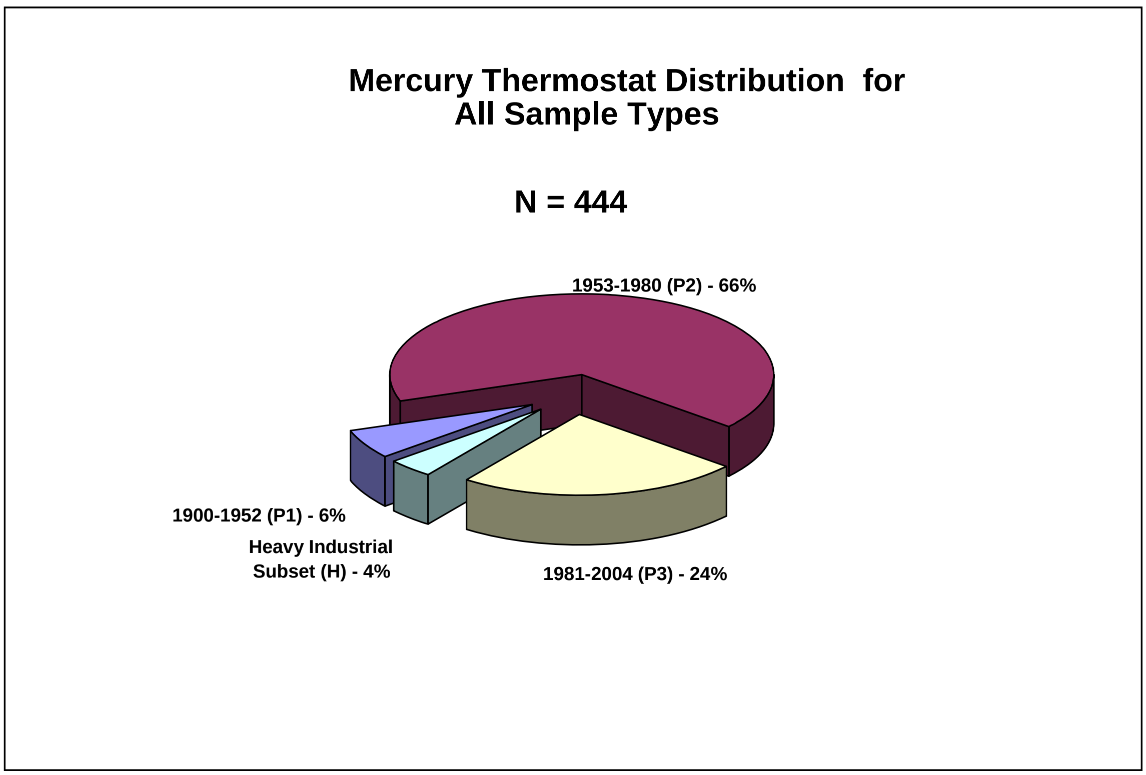


Figure 9. Mercury Thermostat Distribution for all Sample Types

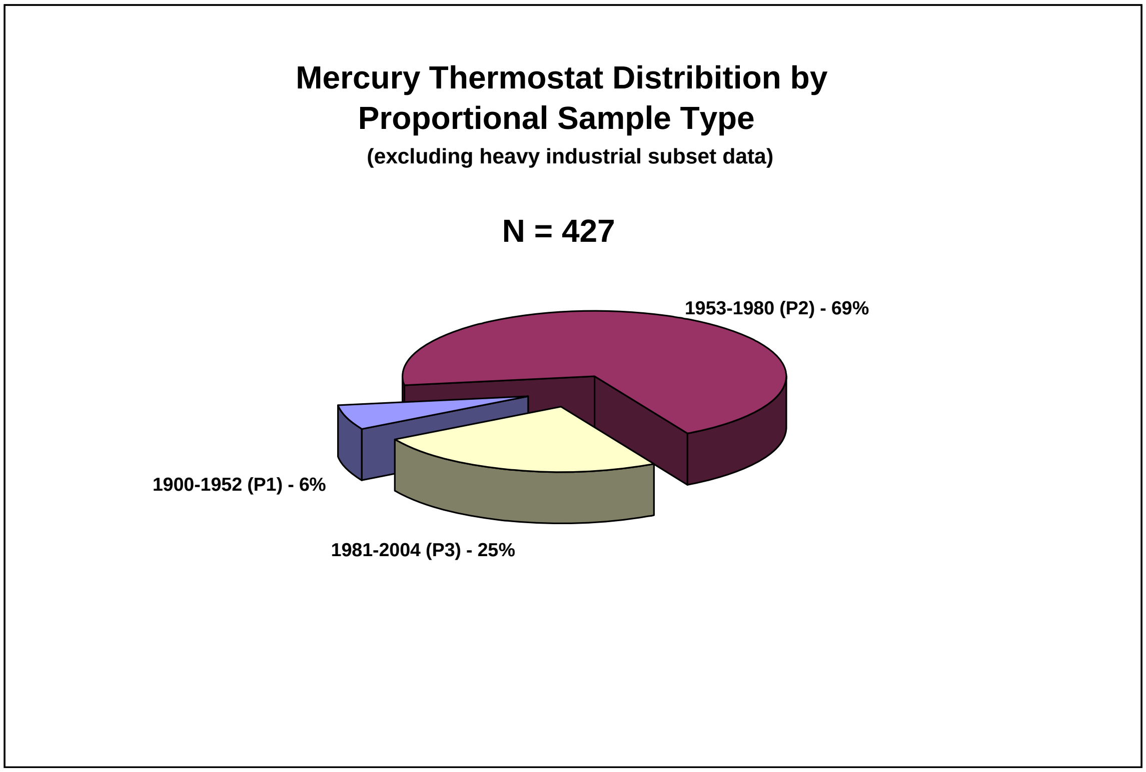


Figure 10. Mercury Thermostat Distribution by Proportional Sample Type

Based on the assumption of the first mercury thermostat manufactured and sold in 1953 and the first digital thermostat manufactured and sold in 1981, data support proportional study design for building age and the number of mercury thermostats observed. Study data indicate the majority of mercury thermostats were observed in buildings built or remodeled during 1953-1980 which correlates with mercury thermostat manufacturing prior to digital technology availability.

When data is weighed against the number of samples sites (opportunities to observe mercury thermostats) and the number of mercury thermostats found, the P2 proportional sample type has 0.5 more mercury thermostats per sample site than the average for all samples (see Table 21).

Table 21. Mercury Thermostat Distribution Weighted by Thermostats/Site

Sample Type	Mercury Thermostats n =	Sample Sites n=	Thermostats/ Site n =
P1 = 1900 – 1952	26	22	1.2
P2 = 1953-1980	295	167	1.8
P3 = 1981- 2004	106	140	1.3
Proportional Total	**427**	**329**	
H = Heavy Industrial	17	17	1.0
Total Sample Set	**444**	**346**	**1.3**

Local Area Characteristics Assessment

From the local area characteristics assessment data collected, variables were selected based on statistical significance for extrapolation. Although survey data collected for building use provided qualitative data for sample sites observed, it did not provide statistically-significant data for estimating mercury thermostats. Table 22 shows the distribution of each building use category. Based on data collected, the “office” building use category was most often observed representing 63 percent of the total building use occurrences documented.

Table 22. Distribution of Building Use by Category and Percent

Building Use Category	Occurrences n =	Total Building Use %
Office	3,764	62.69
Hotel/Motel	314	5.23
Schools	314	5.23
Retail	241	4.01
Food Service	193	3.21
Medical Facility	187	3.11
Equipment/Special Use	160	2.66
Warehouse/Shipping	144	2.40
Church	140	2.33
Other	124	2.07
Manufacturing	91	1.52
Recreation Facility	86	1.43
Storage Area/Shed	85	1.42
Laboratory	52	0.87
Repair Shop	43	0.72
Maintenance	34	0.57
Day Care/Pre-School	21	0.35
Garage	11	0.18
Transportation	0	0.00
Public Use Facility	0	0.00
Totals	**6,004**	**100**

Ceiling height was a significant variable in estimating the number of mercury thermostats and sensors in King County commercial properties. Figure 11 shows the total distribution of thermostats and sensors based on this variable. There are two values for non-mercury sensors. Data for standard ceiling height indicate, of the 2,514 non-mercury sensors observed, 1,583 (96 percent) were found at one sample site (Site ID 18654) representing a possible data anomaly. Data trends in Figure 11 show total and adjusted data. Appendix E provides data used in the analysis of thermostat and sensor distribution by ceiling height.

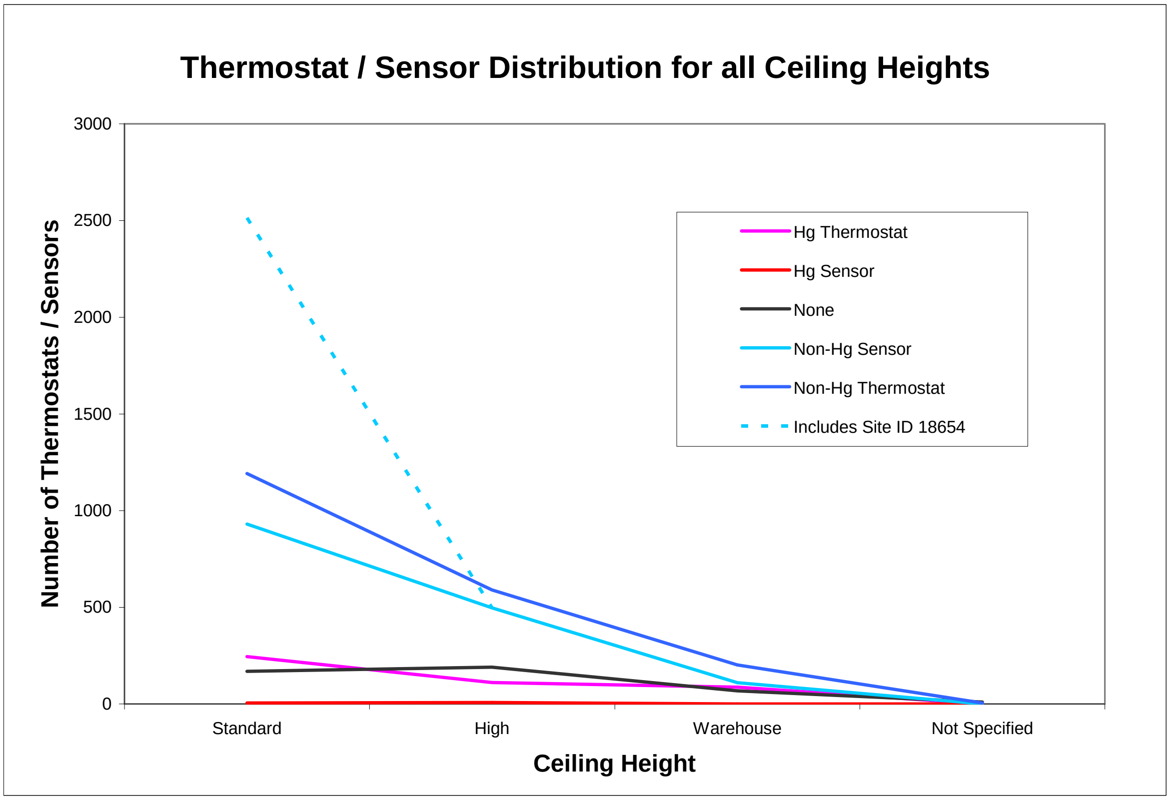


Figure 11. Total Thermostat and Sensor Distribution by Ceiling Height

Data collected for thermostats and sensors showed variable distributions by individual ceiling height. Each figure below shows a comparison for each ceiling height by sample type for each thermostat and sensor type[16].

The total number of occurrences documented for warehouse ceiling height is 468, high ceiling height is 1,395 and standard ceiling height is 4,116. A comparatively small amount of non-specified ceiling heights (n=16) were documented and is not represented graphically.

[16] Figure key shows n = is the number of occurrences for that ceiling height documented for each sample type.

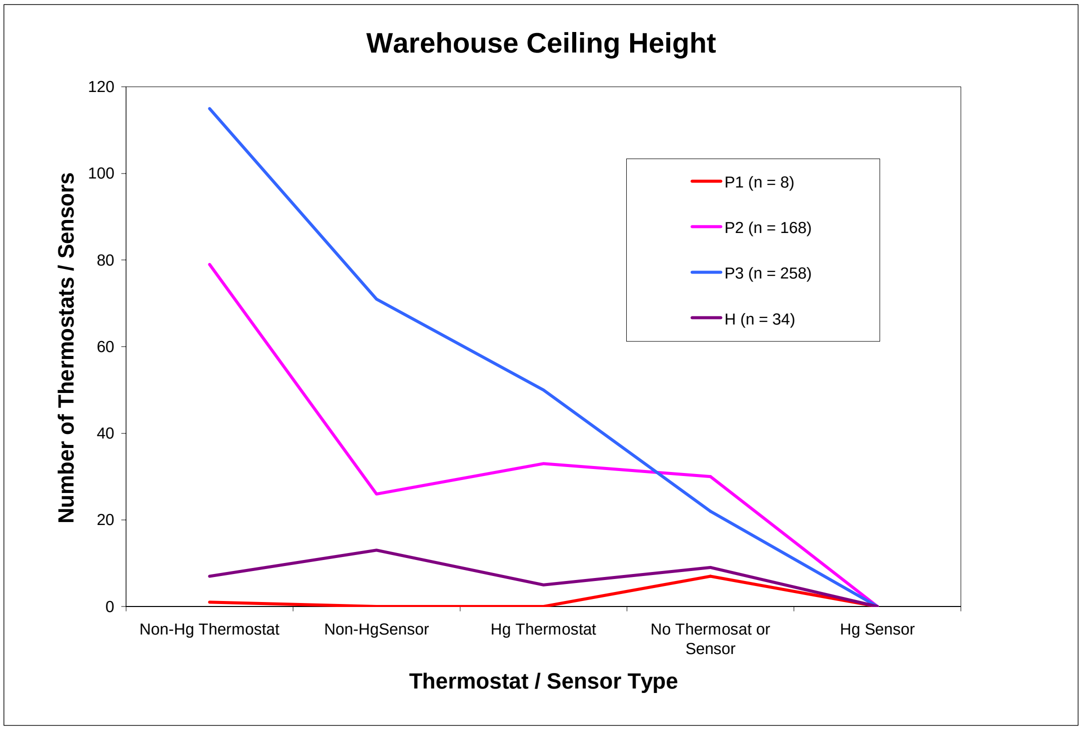


Figure 12. Thermostat and Sensor Distribution by Warehouse Ceiling Height and Sample Type

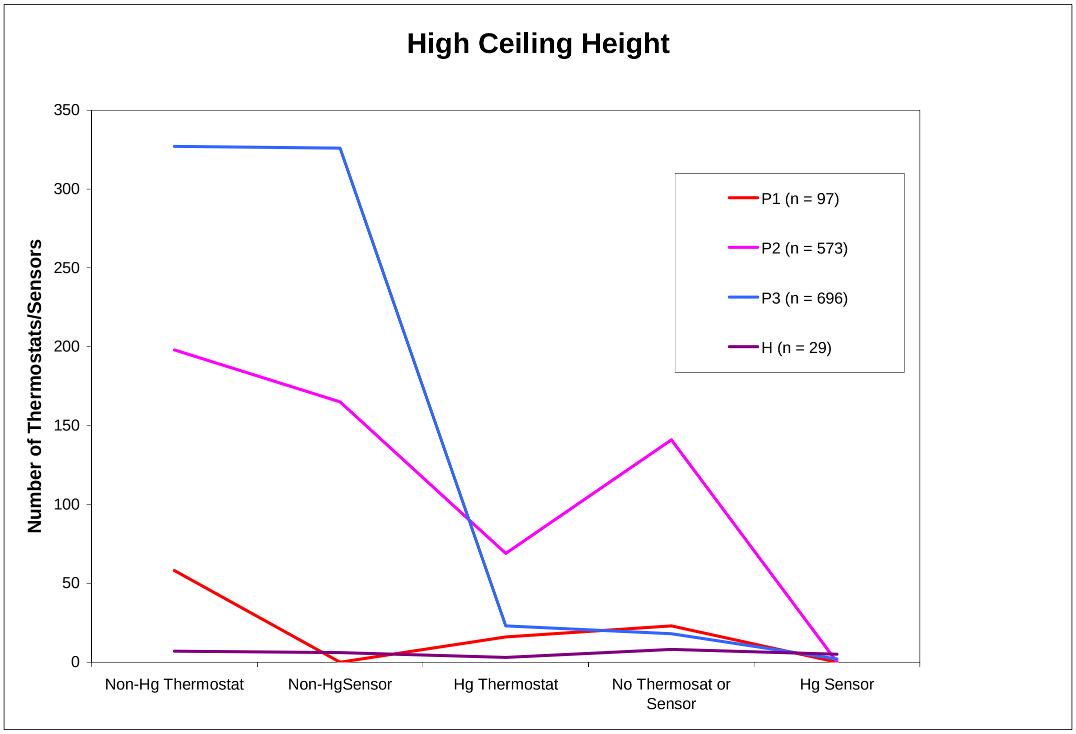


Figure 13. Thermostat and Sensor Distribution by High Ceiling Height and Sample Type

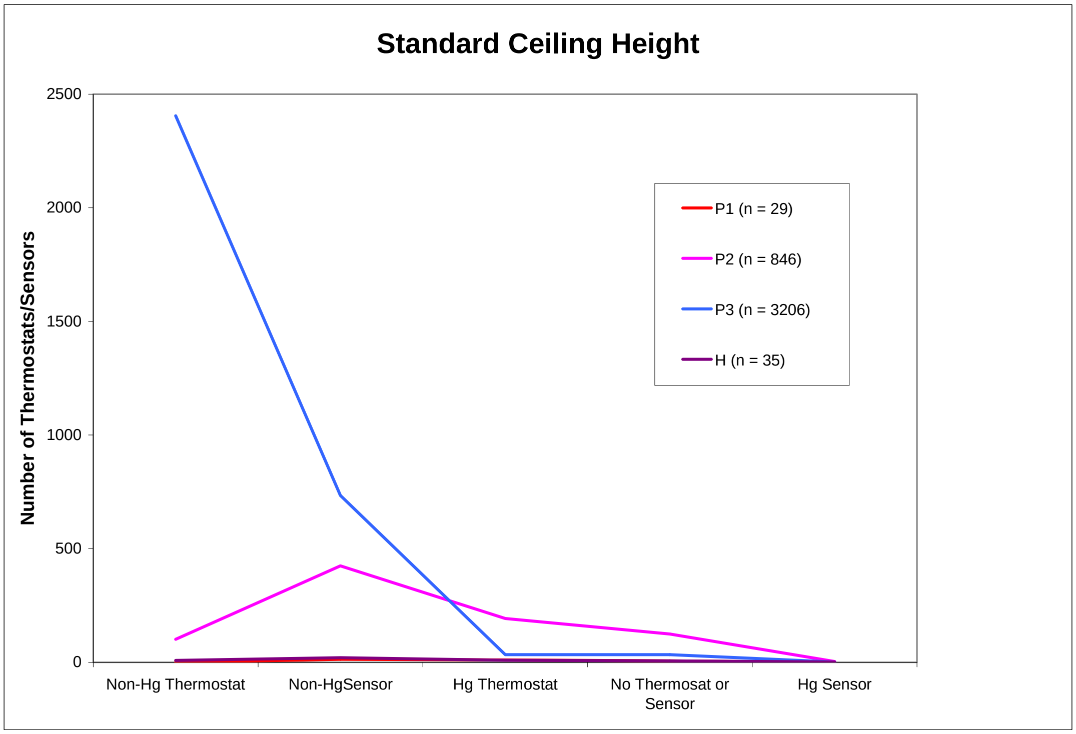


Figure 14. Thermostat and Sensor Distribution by Standard Ceiling Height and Sample Type

Another local area characteristic data variable used for estimating the number of mercury thermostats and sensors in King County commercial properties was building square feet. The square feet central tendency reported in Table 23 show median values for sample site distribution by building square feet. Data indicate buildings built between 1900 and 1981, representing two proportional samples (P1 and P2), have comparable median square feet values. Buildings built 1981-2004, P3 proportional sample, were substantially larger with a building footprint similar in size as the heavy industrial subset (H).

Table 23. Square Feet Distribution of Sample Buildings

Sample Type	MIN ft^2	MEDIAN ft^2	MAX ft^2
P1	540	18,306	27,600
P2	100	16,896	336,330
P3	176	186,800	791,396
H	600	216,224	557,414
All Samples	100	111,415	791,396

Thermostat and Sensor Manufacturers

In a high percentage of thermostats (42 percent), manufacturer type was not determined at the time of data collection and is noted in Table 24 as Not Specified. Excluding those thermostats that were not identified by manufacturer, the manufacturer most often observed for both mercury and non-mercury thermostats was Honeywell accounting for 43 percent of the total thermostats, 59 percent of the mercury thermostats and 37 percent of the non-mercury thermostats observed. The remaining thermostats were distributed among other manufacturers in varying numbers.

Table 24. Thermostat Distribution by Manufacturer

Manufacturer	Thermostats n=	Mercury Thermostats n=	Non-Mercury Thermostats n=
Carrier	14	10	4
Coleman	31	0	31
Comfort	15	0	15
Dayton	6	4	2
DDC Controls	150	0	150
Edwards Engineering	49	49	0
Friedrich	14	0	14
General Electric	161	5	156
Honeywell	604	209	395
Hunter	5	0	5
Invensys	3	0	3
Johnson Controls	17	0	17
Kadet	16	0	16
King	53	4	49
Lennox	6	3	3
Lux	27	9	18
Mitsubishi	5	0	5
Not Specified	1,018	90	930
Other	62	15	47
Powers Johnson	46	4	42
Robertshaw	4	1	3
Totaline	9	0	9
Trane	23	3	20
White-Rogers	95	38	57
Total:	**2,433**	**444**	**1,989**

In a high percentage of sensors (70 percent), manufacturer type was not determined at the time of data collection and is noted in Table 25 as Not Specified. Excluding those sensors that were not identified by manufacturer, the two manufacturers were most often observed for non-mercury sensors, Johnson Controls and Alerton, each with an observation rate of 31 percent of the total non-mercury sensors? A total of 12 mercury sensors were observed primarily categorized in the other category (58 percent) representing various manufacturers not listed. The remaining sensors were distributed among other manufacturers in varying numbers.

Table 25. Sensor Distribution by Manufacturer

Manufacturer	Total Sensors n =	Mercury Sensors n =	Non-Mercury Sensors n =
Accustat	4	3	1
Alerton	299	0	299
Andover Control	86	0	86
Barber-Coleman	9	0	9
BAS	55	0	55
Carrier	17	0	17
Coleman	29	0	29
DDC Controls	2	0	2
General Electric	1	0	1
Honeywell	54	0	54
Invensys	8	0	8
Johnson Controls	297	0	297
King	1	1	0
MCC Powers	20	0	20
Not Specified	2,168	1	2,167
Other	19	7	12
Powers Johnson	6	0	6
Robertshaw	3	0	3
Siemens	17	0	17
Totaline	1	0	1
Trane	31	0	31
White-Rogers	6	0	6
Total:	**3,133**	**12**	**3,121**

Proportional Population Dataset

A systematic sampling strategy was developed from data distributions observed in the KCAO Commercial Properties Database used for data extrapolation. Distribution of the sample set by year built or remodeled was chosen based on the availability of the first mercury thermostat and first digital thermostats manufactured and installed. Data analysis for each of the proportional sample sets show mercury thermostats were observed consistent with data predictions for proportional sample distribution.

P1 Proportional Samples

Buildings built or remodeled for years 1900-1952 were selected proportionally based on the assumption that thermostats installed during this time period do not contain mercury or are past their service life and are longer in use. The P1 proportional population dataset contained 1,936 sample sites representing 6 percent of the total sites available in the KCAO database. A proportional number of random samples were selected for a total of 30 samples.

A total of 22 samples site provided useable data. At least one mercury or non-mercury thermostat was observed in all sites except for 4 (18 percent). As indicated in Table 26, the remaining sites contained:

Table 26. Thermostat Type Observed for Buildings in P1 Proportional Samples

Thermostat Type Observed	Total Number of Sites n = 22	Total P1 Sample Sites %
Mercury (only)	6	27
Non-Mercury (only)	9	41
Mercury & Non-Mercury (both)	3	14
No Thermostat or Sensor Observed	4	18

Data collected for the buildings built or remodeled in 1900-1952 show 98 total thermostats and sensors were observed. Non-mercury thermostats were the most observed thermostat type (74 percent) with an overall distribution of 100 percent thermostats and no sensors observed (see Table 27 for distribution of mercury and non-mercury thermostats and sensors).

Table 27. Total Distribution of Thermostats and Sensors for P1 Proportional Samples

Type	P1 Thermostats n =	Total Proportional Sample %	P1 Sensors n =	Total Proportional Sample %
Mercury	26	0.47	0	0
Non-Mercury	72	1.31	0	0
Total	**98**	1.78	**0**	0

The P1 proportional sample represented 6 percent of the 444 mercury thermostats observed. For the years 1900-1952, it was not unexpected that some mercury thermostats might be found in this proportional sample population based on KCAO data accuracy representing year remodeled and the largely unknown thermostat technology for this building age. The initial hypothesis for sample distribution for this proportional sample did not confirm that no mercury thermostats would be found, however, it did confirm, of the sample sites documented, that thermostats original to buildings built or remodeled in 1900-1952 were no longer in use. Those mercury thermostats observed for the P1 proportional sample were manufactured in or after 1953.

P2 Proportional Samples

The assumption for the years 1953-1980 was expected that the majority of thermostats installed during this time period contained mercury. The P2 proportional population dataset contained 15,316 sample sites representing 50 percent of the total sites available in the KCAO database. A proportional number of random samples were selected for a total of 200 samples.

A total of 167 samples site provided useable data. At least one mercury or non-mercury thermostat was observed in all sites except for 15 (9 percent). As indicated in Table 28 the remaining sites contained:

Table 28. Thermostat Type Observed for Buildings in P2 Proportional Samples

Thermostat Type Observed	Total Number of Sites n = 167	Total P2 Sample Sites %
Mercury (only)	27	16
Non-Mercury (only)	76	46
Mercury & Non-Mercury (both)	49	29
No Thermostat or Sensor Observed	15	9

Data collected for the buildings built or remodeled in 1953-1980 show 1,292 total thermostats and sensors were observed. Non-mercury thermostats were the most observed thermostat type (70 percent) with an overall distribution of 77 percent thermostats and 23 percent sensors observed (see Table 29 for distribution of mercury and non-mercury thermostats and sensors).

Table 29. Total Distribution of Thermostats and Sensors for P2 Proportional Samples

Type	P2 Thermostats	Total Proportional Sample %	P2 Sensors	Total Proportional Sample %
Mercury	295	5.38	3	0.05
Non-Mercury	702	12.80	292	5.32
Total	**997**	18.18	**295**	5.37

The P2 proportional sample represents 66 percent of the 444 mercury thermostats observed. Study data confirmed the hypothesis that the largest number of mercury thermostats would be found in buildings built or remodeled in 1953-1980. The number of sensors documented, 6 percent, is a further indication that mechanical technology is predominately used during this time period which would be expected prior to the availability of digital thermostats and sensors.

P3 Proportional Samples

For years 1981-2004 the assumption is a combination of both mechanical (mercury-containing) and digital thermostats are in use with digital, non-mercury thermostats predominantly in use. The P3 proportional population dataset contained 13,390 sample sites representing 44 percent of the total sites available in the KCAO database. A proportional number of random samples were selected for a total of 160 samples.

A total of 140 samples site provided useable data. At least one mercury or non-mercury thermostat was observed in all sites except for 11 (8 percent). As indicated in Table 30, the remaining sites contained:

Table 30. Thermostat Type Observed for Buildings in P3 Proportional Samples

Thermostat Type Observed	Number of Sites n = 140	Total P3 Sample Sites %
Mercury (only)	12	8.57
Non-Mercury (only)	82	58.57
Mercury & Non-Mercury (both)	35	25.00
No Thermostats or Sensors	11	7.86

Data collected for the P3 proportional population dataset show 4,092 total thermostats and sensors were observed. Non-mercury thermostats were the most observed thermostat type (92 percent) with an overall distribution of 31 percent thermostats and 69 percent sensors observed (see Table 31 for distribution of mercury and non-mercury thermostats and sensors). Of the 2,805 non-mercury sensors observed for the P3 proportional population, 1,583 (56 percent) were found at one sample site (Site ID 18654) representing a possible data anomaly.

Table 31. Total Distribution of Thermostats and Sensors for P3 Proportional Samples

Type	P3 Thermostats	Total Proportional Sample %	P3 Sensors	Total Proportional Sample %
Mercury	106	1.93	3	0.05
Non-Mercury	1181	21.54	2802	51.11
Total	**1,287**	23.47	**2,805**	51.16

The P3 proportional sample represents 24 percent of the 444 mercury thermostats observed. Study data confirmed the hypothesis that mercury thermostats would be found in the 1981-2004 time period in greater numbers than the P1 proportional sample and in less numbers than the P2 proportional sample. The number of sensors documented, 51 percent, is a further indication that digital technology is used for this time period which also correlates with the introduction of the first digital thermostat available in 1981.

Heavy Industrial Data Subset

Buildings that are designed for heavy industrial and manufacturing purposes were thought to have conditions that would be anomalous to most buildings designed for commercial use. Heavy vibration and air particles can often negatively impact more sensitive digital thermostats making the general performance and durability of mercury thermostats a more likely choice for heavy industrial and manufacturing use.

Based on the assumption of anomalous conditions, the heavy industrial subset data population was stratified from the overall population in the KCAO database. Of the 42 buildings identified in the KCAO Database with the predominant use code for Industrial Heavy Manufacturing (495), 22 sites were randomly selected as sample sites.

Mercury thermostats were found in all building age ranges with the largest number of mercury thermostats observed in buildings built prior to 1953. Non-mercury thermostats were found in all buildings with the largest number observed in buildings built after 1980.

Table 32. Thermostat Distribution by Age of Building for Heavy Industrial Subset

Thermostats	1900-1952	1953-1980	1981-2004	Total Observed
Mercury	10	5	1	**16**
Non-Mercury	9	12	14	**35**
Total	**19**	**17**	**15**	**51**

Mercury sensors were observed in buildings built prior to 1953. Non-mercury sensors were found in buildings building after 1953 with the largest number observed in buildings built after 1980.

Table 33. Sensor Distribution by Age of Building for Heavy Industrial Subset

Sensors	1900-1952	1953-1980	1981-2004	Total Observed
Mercury	6	0	0	6
Non-Mercury	0	2	25	27
Total	**6**	**2**	**25**	**33**

A total of 17 samples sites provided useable data. At least one mercury or non-mercury thermostat was observed in all sites except for 2 sample sites (12 percent). As indicated in Table 34 the remaining sites contained:

Table 34. Thermostat Type Observed for Buildings in Heavy Industrial Subset Sample

Thermostat Type Observed	Number of Sites n = 17	Total H Sample Sites %
Mercury (only)	2	12
Non-Mercury (only)	8	47
Mercury & Non-Mercury (both)	5	29
No Thermostat or Sensor Observed	2	12

Data collected for the heavy industrial subset show 84 total thermostats and sensors were observed. Non-mercury thermostats were the most observed thermostat type (40 percent) with an overall distribution of 61 percent thermostats and 39 percent sensors (see Table 35 for distribution of mercury and non-mercury thermostats and sensors).

Table 35. Total Distribution of Thermostats and Sensors for Heavy Industrial Subset Data

Type	H Thermostats n =	% Total Thermostats and Sensors n = 84	H Sensors n =	% Total Thermostats and Sensors n = 84
Mercury	16	20	6	7
Non-Mercury	35	40	27	32
Total	**51**	**61**	**33**	**39**

Building predominant use confirmed as part of the site survey indicates 2 samples sites (12 percent) do not corroborate KCAO heavy industrial predominant use records. Table 36 shows actual building use verified during the site survey, other than Heavy Industrial, and the thermostat and sensor distribution.

Table 36. Non-mercury Sensor and Thermostat Distribution for Observed Predominant Use in Heavy Industrial Subset Data

Site ID	Predominant Use	Thermostat Type	Non-Mercury Sensor n =	Non-Mercury Thermostat n =
32	**Museum**	Sensor	5	5
41	**Vacant for 3 years**	Thermostat	18	3

These data represent 31 percent of the total number of thermostats and sensors observed and 40 percent of data collected for non-mercury sensors. For one sample site, Site ID 41, the largest numbers of sensors were observed in the heavy industrial subset with a count of 18 sensors (31 percent).

Three sample sites, 18% of the total sample sites surveyed, site access was granted and thermostat and building variables documented, however the buildings were unoccupied due to vacancy or renovation and may not be representative of building use when occupied.

Seven sample sites with a warehouse ceiling height, 41 percent of the total samples sites surveyed for the Heavy Industrial subset, were unheated. For sample sites observed with no heat, Table 37 shows the percent of building and use of the unheated space arranged in order of building total square feet.

Table 37. Unheated Space Observed for Heavy Industrial Subset

Building Total Square Feet	Percent Building without Heat %	Total Square Feet without Heat	Unheated Space Use
600	0	0	
2,391	24	580	Equipment/Special Use
2,924	0	0	
3,064	0	0	
3,120	0	0	
4,800	86	4,128	Manufacturing
5,200	0	0	
6,028	0	0	
9,560	93	8,891	Manufacturing
17,845	0	0	
19,096	89	16,995	Manufacturing
21,624	0	0	
24,000	94	22,464	Manufacturing
27,140	0	0	
30,750	57	17,528	Warehouse/Shipping
87,074	25	22,073	Equipment/Special Use
557,414	0	0	

The heavy industrial subset sample data represents 4 percent of the 444 mercury thermostats observed. These subset data were collected as an anomalous dataset from the proportional samples that hypothesized that the majority of thermostats in a heavy industrial building would contain mercury based on their durability in high vibration and particle environments. Data does not confirm this study hypothesis. Data indicates 41 percent of the warehouse height ceiling space, the space within the building most likely to contain manufacturing activities, are unheated. Data also indicates the majority of mercury thermostats were found in buildings built or remodeled prior to 1953 and was associated with ceiling mounted heaters. No strong evidence was found, based on a limited number of samples, there are specific heating/cooling requirements in a heavy industrial setting.

King County Assessors Office Data Trends

It is not unexpected that the composition and distribution of commercial properties will vary from each year of reported data in the KCAO database. Data distribution between years 2004 and 2005 does not show a significant difference based on the proportional and heavy industrial study designation. However looking at the data trend (Table 38), there are fewer buildings built or remodeled in 1900-1952 (P1) and 1943-1980 (P2) and an increased number of buildings built or remodeled in 1981-2004 (P3) with a slight increase in the number of heavy industrial buildings.

Table 38. Data Trends for 2004 and 2005 KCAO Data

Sample Type	2004 KCAO Database n =	2005 KCAO Database n =
1900 – 1952 (P1)	1,936	1,796
1953-1980 (P2)	15,316	15,035
1981- 2004 (P3)	13,390	14,101
Heavy Industrial (H)	42	43
Totals	**30,684**	**30,975**

CONCLUSIONS/RECOMMENDATIONS

Sample Variability

Sample sites were highly variable resulting in a systematic study design that collected a broad range of data to account for variability. It was expected that not all data collected would produce statistically-significant data that was useable for estimating mercury thermostats in King County commercial buildings. However, data variables for building age, square feet, ceiling height and the number of mercury and non-mercury thermostats provided statistically-significant data resulting in useable estimates of the number of mercury-containing thermostats.

Mercury Thermostat Distribution

Distribution of thermostat and sensor data indicate 46 percent of the buildings sampled across all sample types contained at least one non-mercury thermostat. Thirty-nine percent contained at least one mercury thermostat. Although many buildings reported large numbers of non-mercury thermostats and/or sensors, for buildings that report both mercury and non-mercury thermostats less than 3 mercury thermostats were present per building.

Digital technology appears to have reduced the installation of mercury thermostats during renovation and new construction for the majority of space within a building. Although many buildings contain predominantly non-mercury thermostats or sensors, data indicate specific building characteristics and use of space are conducive to continued mercury thermostats use.

Based on building age and age of the HVAC system, study data indirectly confirmed the hypothesis that remodeled buildings can contain mercury thermostats even though digital technology is available. It is presumed that the cost of replacing mercury thermostats that are working properly can preclude thermostat replacement with digital technology. No data was collected on a cost analysis basis.

Ceiling-mounted heaters found in warehouse height ceilings and building space that is not connected to the main HVAC system requiring individual heating are examples of building requirements where mechanical thermostats containing mercury are found. Study data confirm the hypothesis that mechanical thermostats containing mercury are used in conjunction with specific heating and cooling equipment that are based on building requirements

Proportional Sample Data

Proportional sample data indicates the majority of mercury thermostats observed (69 percent) was in buildings built or remodeled 1953-1980. Since mercury thermostat technology had not yet been introduced, the oldest buildings, built or remodeled in 1900-1952, were thought to contain the least amount of mercury thermostats. Data shows 6 percent of the mercury thermostats observed in this proportional dataset. The newest buildings built or remodeled in 1981-2004 show some mercury thermostats (24 percent) with the majority of thermostats observed non-mercury. Data confirm the hypotheses that there is a direct correlation between the year built and/or remodeled and the likelihood that a building contains a mercury thermostat and that the age range of buildings most likely to contain a wall-mounted mercury thermostats is 1953-1980.

Heavy Industrial Subset Data

Data for mercury thermostat distribution in the heavy industrial subset sample show the number of buildings where at least one mercury thermostat was observed was in older buildings, especially built before 1953. Mercury sensors documented for this sample subset were associated with ceiling mounted heaters instead of wall mounted sensors and represent the majority of mercury sensors observed for all data collected for all sample types. Data collected for approximately 30 percent of the heavy industrial sample sites were unoccupied (vacancy or renovation) or was no longer categorized as a heavy industrial use building. Data does not confirm the study hypothesis that buildings built for heavy industrial use would contain more mercury thermostats based on their durability and the building environment where sensitivity to vibration and air particles would preclude other thermostat types.

Based on the study results and study design for this subset population[17], it is recommended that survey data be collected for the remaining 20 buildings in this subset population[18]. Although buildings were considered anomalous by the study design and priorities were made based on available resources, no further conclusions regarding this subset population are possible.

Thermostat Manufacturers

Limited manufacturer data was collected for thermostats and sensors due to the high occurrence of non specified manufacturer data. Data does provide, for those manufacturers identified, a point of reference for potential outreach to thermostat manufacturers.

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[17] Acceptable accuracy criteria at the 95 percent confidence level set at 20 percent for the number of samples drawn for this subset sample.

[18] In order to achieve a high level of accuracy a standard practice in drawing random samples with small populations is to sample the entire population versus in large populations sampled a smaller percentage samples provide a higher level of accuracy.

Non-Thermostat Sources of Mercury

Buildings contain an unknown amount of mercury-containing switches, many that contain far more grams of mercury than a standard mercury thermostat, which are used to regulate equipment. There is also an unknown amount of mercury sensors located in building ducts that regulate building temperature. The scope of this study did not include these potential sources of mercury. These sources of mercury switches, and others to be identified, may contain a significant amount of mercury in commercial buildings. A further study to determine the amount of mercury and frequency of disposal is recommended.

Proportional Trends for Commercial Buildings

KCAO data for years 2004 and 2005 show buildings identified by the study with the highest number of mercury thermostats (66 percent) for years 1953-1980 have fewer buildings in 2005 than in 2004. With fewer buildings built or remodeled in 1900-1952 (P1) and 1943-1980 (P2) and an increased number of buildings built or remodeled in 1981-2004 (P3) the data trend suggests the mercury thermostat replacement and/or disposal rate may be increasing due to renovation and remodeling activities.

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APPENDIX A

DATA COLLECTION INSTRUMENT

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Mercury Thermostat Study

Produced by King County as part of the Local Hazardous Waste Management Program in King County

Initial Visit Date/Time ________	Visit Quality	Site ID Number ________
Follow-up Visit Date/Time ________	1 2 3 4	Parcel/Platt ________
Investigator ________	Questionnaire ☐	Address ________

Contact Name ________

Title ________

Business Name ________

Address ________

____

Phone / e-mail ________

Site Location/Address ________

____

Building Number ________

Year Built ________

Last Remodeled ________

Square Feet ________

Heat/Cooling code ________

Predominant Use

Building Description

Year Built ☐ Year Remodeled ☐ Predominant Use ☐ Building Description ☐ Square Feet ☐

Heating/Cooling System Code

A - Central system - Outside building
B - Central system - Inside building
C - Individual system
D - Special use equipment

Local Area Characteristics Assessment

Heating/Cooling System Code: A B C D

Describe Space

Describe Heating/Cooling Unit: Artifact ☐

Ceiling Height Standard High Warehouse	% of Building ________ Age ________
Thermostats Y / N / ? # **NON**-Hg ________ # **Hg** ________ Total # Tstats Mfg/Model: Photo ☐	Sensors Y / N / ? # **NON**-Hg ________ # **Hg** ________ Total # Sensors Mfg/Model: Photo ☐

Comments:

Heating/Cooling System Code

A - Central system - Outside building
B - Central system - Inside building
C - Individual system
D - Special use equipment

Local Area Characteristics Assessment

Heating/Cooling System Code: A B C D	
Describe Space	
Describe Heating/Cooling Unit: Artifact	
Ceiling Height Standard High Warehouse	% of Building Age
Thermostats Y / N / ? Total #	Sensors Y / N / ? Total #
# **NON**-Hg Tstats	# **NON**-Hg Sensors
# Hg	**# Hg**
Mfg/Model: Photo	Mfg/Model: Photo
Comments:	

Local Area Characteristics Assessment

Heating/Cooling System Code: A B C D	
Describe Space	
Describe Heating/Cooling Unit: Artifact	
Ceiling Height Standard High Warehouse	% of Building Age
Thermostats Y / N / ? Total #	Sensors Y / N / ? Total #
# **NON**-Hg Tstats	# **NON**-Hg Sensors
# Hg	**# Hg**
Mfg/Model: Photo	Mfg/Model: Photo
Comments:	

DATABASE Date Entered ____________Initials ____________QA/QC _____________Initials_______________

APPENDIX B

SAMPLE STATUS TRACKING REPORT

Mercury Thermostat Project

Sample Status as of : **24-Jan-05** **Field Researcher Name**

	Date								
Visit Number	Issued	Received	Complete	Visit Quality	Site ID	Business Name	Address	City	ZIP
1									
2									
3									
4									
5									
6									

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APPENDIX C

PROJECT DATABASE MODULES

Table C.1 Data Fields for Sample/Project Tracking Database Module

Site ID	Unique Identifier assigned to sample site
Sample Status	
Researcher	Unique alpha identifier assigned to each researcher
Issued	Date sample site issued to Researcher
Received	Date sample site data received from Field researcher for data entry
Visit Quality	Researcher designation of site visit quality
Complete	Yes/No - Sample site activities complete with no further action
Site Location	
Business Name	If available, used as sample site locating tool only
KCAO Address	Address as listed in the KCAO Database
KCAO City	City as listed in the KCAO Database
KCAO Zip	Zip as listed in the KCAO Database
QA/QC Status	
QA/QC	Date of completeness review by research lead
Useable Data	Yes/No - Indicates if sample site data is useable for study
Data Quality Report	
VQ 1/2	Report generator indicating sample site information that meets Visit Quality 1and 2 criteria
VQ 3/4	Report generator indicating sample site information that meets Visit Quality 3and 4 criteria
Building Type Report	
H	Report generator indicating sample site information for Heavy Industrial sub sample data
P1	Report generator indicating sample site information for buildings built/remodeled in 1900-1952
P2	Report generator indicating sample site information for buildings built/remodeled in 1953-1980
P3	Report generator indicating sample site information for buildings built/remodeled in 1981-2004

Researcher Report	
Chamberlain	Report generator for all data records collected by individual researcher
Foster	Report generator for all data records collected by individual researcher
Galstad	Report generator for all data records collected by individual researcher
Joyce	Report generator for all data records collected by individual researcher
Rivera	Report generator for all data records collected by individual researcher
VanHooser	Report generator for all data records collected by individual researcher

Table C.2 Data Fields for Site Location Database Module

Site ID	Unique Identifier assigned to sample site
Site Visit Data	
Initial Visit	Date of the first site visit
Follow-Up Visit	Check box indicating one or more site visits occurred
Follow-Up Phone	Check box indicating one or more follow-up phone contacts occurred
Contact Data	
Primary Contact	Pre-determined list - job titles/roles/responsibilities
Multiple Contacts	Check box indicating one more contacts for sample site
Site Refusal	Check box indicating Field researcher was refused entry to site
KCAO Site Verification	
KCAO Site Address	Check box verifying KCAO database site address same as sample site.
Actual Address	Actual address - sample site not the same as KCAO database
Actual City	Actual city - sample site not the same as KCAO database
Actual Zip	Actual zip code - sample site not the same as KCAO database

Table C.3 Data Fields for building Local Area Characteristics Module

Site ID	Unique Identifier assigned to sample site
Local Area Characteristics	Building characteristics that may be associated with thermostat use
Heating Cooling System Code	Look Up Table with predefined system types such as individual heating/cooling unit or special use cooling unit
Building Use	Look Up Table with predefined building use types such as office, retail or warehouse
Ceiling Height	Look Up Table with predefined building ceiling height such as standard, high or warehouse
Percent Building	Field documents the building percent specific Local Area Characteristics pertain to
HVAC	Heating Ventilation Air Conditioning unit
Age	Age of HVAC
Unknown	Age of HVAC Unknown
New	Age of HVAC < one year
Heating/Cooling Unit	Both Primary and Secondary Heating/Cooling Data were documented
Heating Cooling Type	Look Up Table for temperature control type such at heating or cooling
Energy Source	Look Up Table for energy source such as gas or electric
Heating Cooling Source	Look Up Table for carrier source such as air or water
Unit Type	Look Up Table for type of unit such as boiler, furnace or HVAC
Unit Location	Look Up Table for unit location such as ceiling, baseboard or wall
Artifact	Check box indicating heating/cooling unit not in use; building artifact
Appliance	Check box indicating heating/cooling unit was an appliance rather than a building heating/cooling unit, such as a portable electric heater
Thermostats and Sensors	Thermostats and sensor observations
Thermostats and Sensors	Look Up Table for thermostat or sensor designation
Manufacturer	Look Up Table for thermostat/sensor manufacturer
Contains Mercury	Check box indicating thermostat/sensor contain mercury
Unknown Mercury	Check box indicating mercury content of thermostat/sensor is unknown
No Thermostat/Sensor	Check box indicating no thermostat/sensor observed
Unknown	Check box indicating unable to determine if thermostat/sensor present
Artifact	Check box indicating thermostat/sensor is a building artifact and not in use
Photo	Check box indicating a photo was taken of thermostat/sensor by Field researcher for further evaluation

General Information	Data pertaining to overall Site Survey
Site Refusal	Check box indicating Field researcher was refused entry to site
No Heat	Check box indicating no heat present for documented portion of building
Residence	Check box indicating residential property
Unoccupied Space	Check box indicated unoccupied space for documented portion of building
Under Renovation	Check box indicated building renovation in progress for documented portion of building

Table C.4 Data Fields for KCAO Data Verification Module

Site ID	Unique Identifier assigned to sample site
Year Built	
KCAO Year Built	Check box indicating agreement with KCAO database
Unknown	Check box indicating data not available
Actual	Field documents actual year built based on site survey
Year Remodeled	
KCAO Year Remodeled	Check box indicating agreement with KCAO database
Unknown	Check box indicating data not available
Actual	Field documents actual year remodeled observed based on site survey
Predominant Use	
KCAO Predominant Use	Check box indicating agreement with KCAO database
Unknown	Check box indicating data not available
Actual	Look Up Table for predefined actual predominant use based on site survey
Building Description	
KCAO Building Description	Check box indicating agreement with KCAO database
Unknown	Check box indicating data not available
Actual	Look Up Table for predefined actual building description based on site survey
Square Feet	
KCAO Square Feet	Check box indicating agreement with KCAO database
Unknown	Check box indicating data not available
Actual	Field documents actual square feet observed based on site survey

Table C.5 Master Tracking Table

Data Field	Description
Visit Number	Tracked the number of sample sites visited
Date Issued	Date sample site issued to Field researcher
Date Received	Date sample site data received from Field researcher for data entry
Date Complete	Date sample site activities complete with no further action
Visit Quality	Tracked usability of data by visit quality code 1 to 4
Researcher	Field researcher assigned to site
Data Type	Proportional sample code P1, P2, P3 or H
Site ID	Unique identifier assigned to each sample site during random number generation
Major	KCAO numerical designation for Parcel
Minor	KCAO numerical designation for Plat
BldgNbr	KCAO numerical designation for each building within a given Major/Minor
NbrBldgs	KCAO numerical designation for the total number of buildings within a given Major/Minor
Business Name	Business name as listed in KCAO database
Address	Site Address as listed in KCAO database
City	City as listed in KCAO database
Zip	Zip code as listed in KCAO database
Predominant Use	KCAO numerical designation for the predominant use of a building
BldgDescr	KCAO building description
BldgGrossSqFt	KCAO gross square feet that include non-occupied space
YrBuilt	KCAO recorded building year built
EffYr	KCAO last recorded remodel/renovation year for each building
HeatingSystem	KCAO numerical designation for predominant heating system
Number of Stories	KCAO numerical designation for the number of stories within the building

APPENDIX D

KCAO PREDOMINAN USE CODE AND PERCENT RANDOM SAMPLE

KCAO Code	KCAO Description	KCAO Data n=	KCAO Data %	Study Random Sample n=	Sample %
0	No Description	382	1.23	5	1.21
300*	APARTMENT (300)	0	0.00	0	0.00
301	ARMORY (301)	6	0.02	0	0.00
302	AUDITORIUM (302)	148	0.48	2	0.49
303	AUTOMOBILE SHOWROOM (303)	63	0.20	1	0.24
304	BANK (304)	329	1.06	5	1.21
305	BARN (305)	38	0.12	0	0.00
306	BOWLING ALLEY (306)	20	0.06	1	0.24
308	CHURCH WITH SUNDAY SCHOOL (308)	130	0.42	3	0.73
309	CHURCH (309)	1,069	3.45	17	4.13
310	CITY CLUB (310)	7	0.02	0	0.00
311	CLUBHOUSE (311)	298	0.96	6	1.46
313	CONVALESCENT HOSPITAL (313)	89	0.29	2	0.49
314	COUNTRY CLUB (314)	17	0.05	0	0.00
315	CREAMERY (315)	5	0.02	0	0.00
316	DAIRY (316)	14	0.05	1	0.24
317	DAIRY SALES BUILDING (317)	0	0.00	0	0.00
318	DEPARTMENT STORE (318)	32	0.10	2	0.49
319	DISCOUNT STORE (319)	227	0.73	4	0.97
320	DISPENSARY (320)	3	0.01	0	0.00
321	DORMITORY (321)	85	0.27	1	0.24
322	FIRE STATION (STAFFED) (322)	159	0.51	2	0.49
323	FRATERNAL BUILDING (323)	114	0.37	3	0.73
324	FRATERNITY HOUSE (324)	52	0.17	1	0.24
326	GARAGE, STORAGE (326)	419	1.35	8	1.94
327	GOVERNMENT BUILDING (327)	147	0.47	2	0.49
328	HANGAR, STORAGE (328)	92	0.30	0	0.00
329	HANGAR, MAINTENANCE & OFFICE (329)	33	0.11	0	0.00
330*	HOME FOR THE ELDERLY (330)	0	0.00	0	0.00
331	HOSPITAL (331)	53	0.17	0	0.00

KCAO Code	KCAO Description	KCAO Data n=	KCAO Data %	Study Random Sample n=	Sample %
332	HOTEL, LIMITED (332)	70	0.23	0	0.00
335	JAIL-CORRECTIONAL FACILITY (335)	7	0.02	0	0.00
336	LAUNDROMAT (336)	66	0.21	0	0.00
337	LIBRARY, PUBLIC (337)	77	0.25	1	0.24
338	LOFT (338)	70	0.23	1	0.24
339	LUMBER STORAGE SHED, HORIZONTAL (339)	73	0.24	0	0.00
340	MARKET (340)	146	0.47	2	0.49
341	MEDICAL OFFICE (341)	744	2.40	8	1.94
342	MORTUARY (342)	45	0.15	0	0.00
343	MOTEL, LIMITED (343)	263	0.85	3	0.73
344	OFFICE BUILDING (344)	4,690	15.14	62	15.05
345	PARKING STRUCTURE (345)	151	0.49	1	0.24
346	POST OFFICE (346)	41	0.13	0	0.00
348	RECTORY (348)	371	1.20	2	0.49
349	FAST FOOD RESTAURANT (349)	342	1.10	3	0.73
350	RESTAURANT, TABLE SERVICE (350)	1,131	3.65	18	4.37
352*	MULTIPLE RESIDENCE (LOW RISE) (352)	0	0.00	0	0.00
353	RETAIL STORE (353)	3,663	11.83	45	10.92
365	ELEMENTARY SCHOOL (ENTIRE) (365)	1,004	3.24	23	5.58
366	JUNIOR HIGH SCHOOL (ENTIRE) (366)	65	0.21	2	0.49
377	COLLEGE (ENTIRE) (377)	78	0.25	0	0.00
378	STABLE (378)	37	0.12	0	0.00
379	THEATER, LIVE STAGE (379)	23	0.07	2	0.49
380	THEATER, CINEMA (380)	41	0.13	1	0.24
381	VETERINARY HOSPITAL (381)	108	0.35	1	0.24
384	BARBER SHOP (384)	93	0.30	3	0.73
386	MINI-WAREHOUSE (386)	568	1.83	6	1.46
387	TRANSIT WAREHOUSE (387)	39	0.13	0	0.00
388	UNDERGROUND PARKING STRUCTURE (388)	2	0.01	0	0.00
391	MATERIAL STORAGE BUILDING (391)	44	0.14	1	0.24
392	INDUSTRIAL ENGINEERING BUILDING (392)	60	0.19	1	0.24
405	SKATING RINK (405)	8	0.03	0	0.00
406	STORAGE WAREHOUSE (406)	3,397	10.97	39	9.47
407	WAREHOUSE, DISTRIBUTION (407)	965	3.12	16	3.88
409	T-HANGAR (409)	5	0.02	0	0.00
410	AUTOMOTIVE CENTER (410)	53	0.17	0	0.00
412	NEIGHBORHOOD SHOPPING CENTER (412)	8	0.03	0	0.00
413	COMMUNITY SHOPPING CENTER (413)	13	0.04	0	0.00

KCAO Code	KCAO Description	KCAO Data n=	KCAO Data %	Study Random Sample n=	Sample %
414	REGIONAL SHOPPING CENTER (414)	9	0.03	0	0.00
416	TENNIS CLUB, INDOOR (416)	9	0.03	0	0.00
417	HANDBALL-RACQUETBALL CLUB (417)	5	0.02	0	0.00
418	HEALTH CLUB (418)	28	0.09	0	0.00
419	CONVENIENCE MARKET (419)	409	1.32	7	1.70
423	MINI-LUBE GARAGE (423)	42	0.14	1	0.24
424	GROUP CARE HOME (424)	65	0.21	1	0.24
426	DAY CARE CENTER (426)	217	0.70	1	0.24
427	FIRE STATION (VOLUNTEER) (427)	17	0.05	1	0.24
428	HORSE ARENA (428)	8	0.03	1	0.24
431	OUTPATIENT SURGICAL CENTER (431)	0	0.00	0	0.00
432	RESTROOM BUILDING (432)	137	0.44	1	0.24
441	COCKTAIL LOUNGE (441)	8	0.03	0	0.00
442	BAR/TAVERN (442)	77	0.25	2	0.49
444	DENTAL OFFICE/CLINIC (444)	52	0.17	0	0.00
446	SUPERMARKET (446)	129	0.42	2	0.49
447	COLD STORAGE FACILITIES (447)	40	0.13	0	0.00
451	MULTIPLE RESIDENCE (SENIOR CITIZEN) (451)	125	0.40	0	0.00
453	INDUSTRIAL FLEX BUILDINGS (453)	40	0.13	0	0.00
455	AUTO DEALERSHIP, COMPLETE (455)	59	0.19	0	0.00
458	WAREHOUSE DISCOUNT STORE (458)	32	0.10	0	0.00
459	MIXED RETAIL W/RES. UNITS (459)	251	0.81	0	0.00
468	SHED, MATERIAL STORAGE (468)	166	0.54	0	0.00
470	EQUIPMENT (SHOP) BUILDING (470)	359	1.16	3	0.73
471	LIGHT COMMERCIAL UTILITY BUILDING (471)	91	0.29	3	0.73
472	EQUIPMENT SHED (472)	274	0.88	3	0.73
475	POULTRY HOUSE-FLOOR OPERATION (475)	0	0.00	0	0.00
477	FARM UTILITY BUILDING (477)	44	0.14	0	0.00
481	MUSEUM (481)	37	0.12	0	0.00
482	CONVENTION CENTER (482)	8	0.03	0	0.00
483	FITNESS CENTER (483)	34	0.11	1	0.24
484	HIGH SCHOOL (ENTIRE) (484)	126	0.41	2	0.49
485	NATATORIUM (485)	20	0.06	0	0.00
486	FIELD HOUSES (486)	28	0.09	0	0.00
487	VOCATIONAL SCHOOLS (487)	34	0.11	0	0.00
489	JAIL - POLICE STATION (489)	4	0.01	0	0.00
490	KENNELS (490)	6	0.02	0	0.00
491	GOVERNMENT COMMUNITY SERVICE BUILDING	83	0.27	1	0.24

KCAO Code	KCAO Description	KCAO Data n=	KCAO Data %	Study Random Sample n=	Sample %
	(491)				
494	INDUSTRIAL LIGHT MANUFACTURING (494)	1,556	5.02	14	3.40
495	INDUSTRIAL HEAVY MANUFACTURING (495)	42	0.14	22	5.34
496	LABORATORIES (496)	28	0.09	0	0.00
497	COMPUTER CENTER (497)	0	0.00	0	0.00
498	BROADCAST FACILITIES (498)	8	0.03	1	0.24
525	MINI WAREHOUSE, HI-RISE (525)	66	0.21	1	0.24
527	MUNICIPAL SERVICE GARAGE (527)	10	0.03	0	0.00
528	GARAGE, SERVICE REPAIR (528)	1,820	5.88	18	4.37
529	SNACK BAR (529)	33	0.11	1	0.24
530	CAFETERIA (530)	26	0.08	0	0.00
531	MINI-MART CONVENIENCE STORE (531)	46	0.15	0	0.00
532	FLORIST SHOP (532)	5	0.02	0	0.00
533	WAREHOUSE FOOD STORE (533)	3	0.01	0	0.00
534	WAREHOUSE SHOWROOM STORE (534)	39	0.13	1	0.24
551	ROOMING HOUSE (551)	161	0.52	6	1.46
573	ARCADE (573)	6	0.02	0	0.00
574	VISITOR CENTER (574)	11	0.04	0	0.00
636	??????	6	0.02	0	0.00
701	BASEMENT, FINISHED (701)	20	0.06	0	0.00
702	BASEMENT, SEMIFINISHED (702)	5	0.02	0	0.00
703	BASEMENT, UNFINISHED (703)	150	0.48	2	0.49
704	BASEMENT, DISPLAY (704)	0	0.00	0	0.00
705	BASEMENT, OFFICE (705)	46	0.15	2	0.49
706	BASEMENT, PARKING (706)	18	0.06	0	0.00
707	BASEMENT, RESIDENT LIVING (707)	0	0.00	0	0.00
708	BASEMENT, STORAGE (708)	0	0.00	0	0.00
709	BASEMENT, RETAIL (709)	0	0.00	0	0.00
810	WAREHOUSE OFFICE (810)	136	0.44	1	0.24
820	OPEN OFFICE (820)	215	0.69	0	0.00
830	MIXED USE RETAIL (830)	176	0.57	2	0.49
840	MIXED USE OFFICE (840)	164	0.53	1	0.24
841	HOTEL, FULL SERVICE (841)	76	0.25	1	0.24
842	HOTEL, SUITE (842)	39	0.13	1	0.24
843	MOTEL, FULL SERVICE (843)	35	0.11	0	0.00
844	MOTEL, SUITE (844)	60	0.19	0	0.00
845	CONDO, OFFICE (845)	44	0.14	0	0.00
846	CONDO, RETAIL (846)	36	0.12	0	0.00

KCAO Code	KCAO Description	KCAO Data n=	KCAO Data %	Study Random Sample n=	Sample %
847	MIXED USE-OFFICE CONDO (847)	20	0.06	0	0.00
848	MIXED USE-RETAIL CONDO (848)	28	0.09	0	0.00
849	CONDO, STORAGE (849)	2	0.01	0	0.00
850	CONDO, PARKING STRUCTURE (850)	0	0.00	0	0.00
851	UNDERGROUND CONDO PARKING (851)	0	0.00	0	0.00
852	CONDO HOTEL, FULL SERVICE (852)	0	0.00	0	0.00
853	CONDO HOTEL, LIMITED SERVICE (853)	1	0.00	0	0.00
860	LINE RETAIL (860)	171	0.55	1	0.24
	Commercial Building Total:	**30,684**		**412**	

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APPENDIX E

THERMOSTATS AND SENSOR DISTRIBUTION BY CEILING HEIGHT AND SAMPLE TYPE

Site ID	Warehouse Ceiling Height	High Ceiling Height	Standard Ceiling Height	Ceiling Height Not Specified
P1	n = 8	n = 97	n = 29	n = 0
Mercury Thermostat	0	16	10	0
Non-Mercury Thermostat	1	58	13	0
Mercury Sensor	0	0	0	0
Non-Mercury Sensor	0	0	0	0
No Thermostat or Sensor	7	23	6	0
P2	n = 168	n = 573	n = 846	n = 8
Mercury Thermostat	33	69	193	0
Non-Mercury Thermostat	79	198	425	0
Mercury Sensor	0	0	3	0
Non-Mercury Sensor	26	165	101	0
No Thermostat or Sensor	30	141	124	8
P3	n = 258	n = 696	n = 3206	n = 8
Mercury Thermostat	50	23	33	0
Non-Mercury Thermostat	115	327	734	5
Mercury Sensor	0	2	1	0
Non-Mercury Sensor	71	326	2,405	0
No Thermostat or Sensor	22	18	33	3
H	n = 34	n = 29	n = 35	n = 0
Mercury Thermostat	5	3	9	0
Non-Mercury Thermostat	7	7	20	0
Mercury Sensor	0	5	1	0
Non-Mercury Sensor	13	6	8	0
No Thermostat or Sensor	9	8	6	0
Total	n = 468	n = 1,395	n = 4,116	n = 16

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APPENDIX F

DATA QA/QC BY RESEARCHER – MILESTONE REPORT

Mercury Thermostat Project

Milestone Report - Data QA/QC

Visit Number	Date		Week	Visit Quality	Field Researcher	Site ID	City	BldgDescr	BldgNetSqFt	Number of Stories	QA/QC Document Check							Not Useable Data
	Issued	Received									KCAO Verification	Heating/Cooling Des.	#Thermostats	#Sensors	Ceiling Height	%building use	Space Description	

Week #

Week 1 totals:					**# Received**			**% Useable Data**										

Data Summary:

Data Errors by Category

KCAO Verification

Heating/Cooling Des.

#Thermostats

#Sensors

Ceiling Height

%building use

Space Description

Total number of errors

Percent error rate

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APPENDIX G

KCAO VERIFICATION INDEX DATA BY RESEARCHER

Table G.1 Researcher A

Index Data Calculation Summary

Comparable Index		
MIN n=66	MAX n=66	MEDIAN n=66
3993.38	19725.72	6295.16

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1962	19.62	936	6.84	470	47.00	6308.93
P2	1957	19.57	35926	10.49	306	30.60	6281.38
P2	1939	19.39	544	6.30	384	38.40	4690.05
P2	1961	19.61	960	6.87	344	34.40	4632.32
P2	1973	19.73	640	6.46	471	47.10	6004.53
P2	1959	19.59	46669	10.75	407	40.70	8571.78
P2	1923	19.23	6634	8.80	344	34.40	5821.28
P2	1924	19.24	2600	7.86	344	34.40	5204.35
P2	1945	19.45	3675	8.21	353	35.30	5636.39
P2	1975	19.75	567	6.34	348	34.80	4357.73
P2	1956	19.56	378	5.93	344	34.40	3993.38
P2	1952	19.52	44496	10.70	344	34.40	7187.04
P2	1954	19.54	7476	8.92	344	34.40	5995.44
P2	1948	19.48	13196	9.49	309	30.90	5710.93
P2	1946	19.46	1686	7.43	326	32.60	4713.63
P2	1964	19.64	6300	8.75	344	34.40	5910.49
P2	1947	19.47	7628	8.94	353	35.30	6144.09
P2	1955	19.55	4322	8.37	341	34.10	5580.88
P2	1964	19.64	8376	9.03	406	40.60	7202.87

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1970	19.70	12180	9.41	406	40.60	7524.35
P2	1967	19.67	16941	9.74	309	30.90	5918.48
P2	1964	19.64	22466	10.02	309	30.90	6080.75
P2	1962	19.62	71343	11.18	365	36.50	8002.94
P2	1930	19.30	2048	7.62	350	35.00	5150.43
P2	1960	19.60	2288	7.74	344	34.40	5215.54
P3	1987	19.87	2497	7.82	419	41.90	6512.93
P2	1964	19.64	33160	10.41	313	31.30	6398.81
P2	1902	19.02	3914	8.27	384	38.40	6041.83
P3	1973	19.73	47940	10.78	340	34.00	7229.90
P3	1904	19.04	3483	8.16	344	34.40	5341.75
P3	1989	19.89	37960	10.54	407	40.70	8535.84
P3	1993	19.93	33146	10.41	407	40.70	8443.01
P3	1999	19.99	2000	7.60	344	34.40	5226.81
P3	1978	19.78	17516	9.77	0		
P3	1978	19.78	60448	11.01	406	40.60	8841.41
P3	1986	19.86	7000	8.85	406	40.60	7138.85
P3	1987	19.87	35970	10.49	0		
P3	1986	19.86	10856	9.29	344	34.40	6348.47
P3	1976	19.76	791396	13.58	344	34.40	9231.98
P3	2003	20.03	56035	10.93	340	34.00	7446.09
P3	1967	19.67	2460	7.81	419	41.90	6435.07
P3	1999	19.99	6000	8.70	344	34.40	5982.27
P3	1968	19.68	23177	10.05	494	49.40	9771.42
P3	2000	20.00	24500	10.11	327	32.70	6609.60
P3	2002	20.02	124816	11.73	406	40.60	9538.02
P3	1991	19.91	51000	10.84	494	49.40	10661.31
P3	1995	19.95	86430	11.37	494	49.40	11202.61
P3	1981	19.81	4900	8.50	350	35.00	5891.39
P3	1952	19.52	67720	11.12	498	49.80	10812.76
P3	1962	19.62	1665	7.42	353	35.30	5137.31
P3	1983	19.83	186800	12.14	341	34.10	8207.61
P3	2000	20.00	2500	7.82	528	52.80	8262.19
P3	1995	19.95	122638	11.72	344	34.40	8041.14
P3	1999	19.99	122942	11.72	842	84.20	19725.72
P3	2000	20.00	400	5.99	432	43.20	5176.63
P3	1982	19.82	8808	9.08	344	34.40	6193.15
P3	1982	19.82	1200	7.09	406	40.60	5705.33

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P3	1992	19.92	15888	9.67	406	40.60	7823.32
P3	1987	19.87	28481	10.26	353	35.30	7194.37
P3	1969	19.69	7960	8.98	344	34.40	6083.96
P3	1974	19.74	17600	9.78	406	40.60	7834.64
P3	1985	19.85	5000	8.52	353	35.30	5968.04
P3	2000	20.00	57132	10.95	344	34.40	7535.75
P3	1990	19.90	1620	7.39	423	42.30	6220.83
P3	1903	19.03	7852	8.97	381	38.10	6502.57
P3	1980	19.80	22674	10.03	309	30.90	6135.93
P3	2000	20.00	53040	10.88	326	32.60	7092.98
P2	1922	19.22	6932	8.84	353	35.30	6000.29

Table G.2 Researcher B

Index Data Calculation Summary

Comparable Index		
MIN n=72	**MAX n=72**	**MEDIAN n=72**
4431.93	9902.88	6060.71

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P1	1940	19.40	3824	8.25	309	30.90	4944.98
P1	1914	19.14	16612	9.72	324	32.40	6026.41
P1	1910	19.10	1130	7.03	344	34.40	4618.97
P1	1923	19.23	2412	7.79	353	35.30	5286.79
P1	1948	19.48	696	6.55	353	35.30	4500.87
P1	1949	19.49	4212	8.35	353	35.30	5741.81
P1	1919	19.19	25128	10.13	365	36.50	7096.62
P1	1900	19.00	2668	7.89	384	38.40	5755.88
P2	1926	19.26	4908	8.50	353	35.30	5778.03
P2	1970	19.70	4920	8.50	323	32.30	5409.31
P2	1969	19.69	432	6.07	470	47.00	5615.90
P2	1976	19.76	1402	7.25	344	34.40	4925.19
P2	1968	19.68	4256	8.36	344	34.40	5657.00
P2	1956	19.56	1920	7.56	343	34.30	5072.12
P2	1956	19.56	5481	8.61	344	34.40	5792.72
P2	1952	19.52	21900	9.99	407	40.70	7940.07
P2	1928	19.28	148110	11.91	345	34.50	7919.20
P2	1926	19.26	6000	8.70	353	35.30	5914.61
P2	1959	19.59	113173	11.64	343	34.30	7819.11
P2	1926	19.26	1120	7.02	350	35.00	4732.91
P2	1934	19.34	1982	7.59	353	35.30	5182.98
P2	1972	19.72	3715	8.22	344	34.40	5576.28
P2	1926	19.26	2880	7.97	350	35.00	5369.57
P2	1962	19.62	3738	8.23	353	35.30	5697.42
P2	1956	19.56	1264	7.14	326	32.60	4554.16
P2	1942	19.42	2622	7.87	353	35.30	5396.25

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1962	19.62	5120	8.54	534	53.40	8948.38
P2	1946	19.46	11174	9.32	309	30.90	5605.06
P2	1961	19.61	2930	7.98	353	35.30	5525.93
P2	1962	19.62	21723	9.99	365	36.50	7151.37
P2	1959	19.59	15856	9.67	322	32.20	6100.64
P2	1962	19.62	12394	9.42	303	30.30	5603.01
P2	1940	19.40	9583	9.17	528	52.80	9390.71
P2	1966	19.66	2400	7.78	419	41.90	6411.46
P2	1924	19.24	8528	9.05	350	35.00	6095.02
P2	1950	19.50	1030	6.94	353	35.30	4775.30
P2	1958	19.58	18660	9.83	407	40.70	7836.88
P2	1916	19.16	4050	8.31	344	34.40	5474.83
P2	1900	19.00	1880	7.54	406	40.60	5815.61
P2	1948	19.48	16600	9.72	406	40.60	7685.18
P2	1964	19.64	10800	9.29	406	40.60	7405.55
P2	1915	19.15	3183	8.07	551	55.10	8510.52
P3	1988	19.88	13800	9.53	353	35.30	6689.51
P3	1960	19.60	5600	8.63	353	35.30	5971.29
P3	1996	19.96	32760	10.40	406	40.60	8425.45
P3	1988	19.88	8063	9.00	528	52.80	9441.77
P3	2001	20.01	53621	10.89	302	30.20	6580.67
P3	1981	19.81	1556	7.35	311	31.10	4528.19
P3	1999	19.99	19861	9.90	344	34.40	6805.40
P3	2001	20.01	1848	7.52	326	32.60	4906.70
P3	1989	19.89	6848	8.83	528	52.80	9274.99
P3	1988	19.88	10777	9.29	365	36.50	6737.50
P3	1977	19.77	4188	8.34	344	34.40	5671.92
P3	2003	20.03	25000	10.13	407	40.70	8255.44
P3	1991	19.91	14272	9.57	365	36.50	6951.80
P3	1998	19.98	9266	9.13	344	34.40	6277.98
P3	1970	19.70	1704	7.44	419	41.90	6141.80
P3	1985	19.85	2080	7.64	349	34.90	5292.81
P3	1972	19.72	1716	7.45	419	41.90	6153.84
P3	1998	19.98	67037	11.11	446	44.60	9902.88
P3	1999	19.99	9840	9.19	406	40.60	7461.97
P3	2003	20.03	52000	10.86	365	36.50	7938.96
P3	1960	19.60	19220	9.86	406	40.60	7849.14
P3	1925	19.25	680	6.52	353	35.30	4431.93

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P3	1959	19.59	2222	7.71	426	42.60	6431.06
P3	1978	19.78	20125	9.91	341	34.10	6684.09
P3	2000	20.00	302186	12.62	318	31.80	8025.56
P3	1995	19.95	3980	8.29	350	35.00	5787.82
P3	1985	19.85	3705	8.22	311	31.10	5072.91
P3	1981	19.81	87807	11.38	344	34.40	7757.03
P3	1992	19.92	40059	10.60	392	39.20	8275.68
P3	1995	19.95	1600	7.38	419	41.90	6167.11

Table G.3 Researcher C

Index Data Calculation Summary

Comparable Index		
MIN n=71	**MAX n=71**	**MEDIAN n=71**
4352.79	14569.95	7014.21

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
H	1920	19.20	27140	10.21	495	49.50	9702.41
H	1959	19.59	9560	9.17	495	49.50	8887.68
P1	1920	19.20	9940	9.20	309	30.90	5460.74
P1	1950	19.50	1755	7.47	406	40.60	5914.18
P1	1912	19.12	988	6.90	840	84.00	11075.02
P2	1901	19.01	2160	7.68	344	34.40	5020.89
P2	1974	19.74	11250	9.33	528	52.80	9722.44
P2	1979	19.79	106364	11.57	353	35.30	8085.88
P2	1946	19.46	11859	9.38	365	36.50	6663.12
P2	1905	19.05	3372	8.12	353	35.30	5462.61
P2	1971	19.71	2031	7.62	344	34.40	5164.02
P2	1957	19.57	5552	8.62	365	36.50	6158.68
P2	1969	19.69	4500	8.41	350	35.00	5797.01
P2	1970	19.70	10588	9.27	309	30.90	5641.39
P2	1964	19.64	4000	8.29	494	49.40	8047.02
P2	1950	19.50	10700	9.28	407	40.70	7363.48
P2	1980	19.80	7500	8.92	386	38.60	6819.41
P2	1961	19.61	12062	9.40	313	31.30	5768.31
P2	1960	19.60	76922	11.25	365	36.50	8048.64
P2	1974	19.74	10400	9.25	406	40.60	7413.01
P2	1977	19.77	7600	8.94	528	52.80	9327.80
P2	1977	19.77	3690	8.21	344	34.40	5585.82
P2	1961	19.61	45906	10.73	366	36.60	7704.32
P2	1960	19.60	5842	8.67	341	34.10	5796.57
P2	1957	19.57	1204	7.09	528	52.80	7329.59
P2	1938	19.38	8820	9.08	350	35.00	6162.20

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1973	19.73	3,200	8.07	406	40.60	6,465.10
P2	1975	19.75	4,080	8.31	0		
P2	1934	19.34	2,912	7.98	350	35.00	5,399.36
P2	1964	19.64	7,000	8.85	494	49.40	8,589.97
P2	1908	19.08	9,900	9.20	830	83.00	14,569.95
P2	1960	19.60	2,509	7.83	344	34.40	5,277.71
P3	2000	20.00	68,040	11.13	407	40.70	9,058.07
P3	1987	19.87	228,044	12.34	407	40.70	9,977.28
P3	1992	19.92	2,820	7.94	528	52.80	8,355.83
P3	1982	19.82	13,125	9.48	494	49.40	9,284.17
P3	1995	19.95	3,584	8.18	344	34.40	5,616.68
P3	1955	19.55	22,022	10.00	484	48.40	9,462.01
P3	1974	19.74	14,162	9.56	344	34.40	6,490.63
P3	2004	20.04	3,043	8.02	304	30.40	4,886.28
P3	1990	19.90	62,900	11.05	319	31.90	7,014.21
P3	1988	19.88	103,702	11.55	407	40.70	9,344.70
P3	1988	19.88	115,920	11.66	407	40.70	9,434.82
P3	1989	19.89	7,272	8.89	406	40.60	7,180.42
P3	2003	20.03	99,433	11.51	491	49.10	11,317.06
P3	1970	19.70	56,827	10.95	365	36.50	7,871.99
P3	1928	19.28	1,482	7.30	350	35.00	4,926.81
P3	1985	19.85	5,854	8.67	344	34.40	5,923.56
P3	2000	20.00	476	6.17	353	35.30	4,352.79
P3	2001	20.01	213,832	12.27	344	34.40	8,448.01
P3	1994	19.94	8,800	9.08	343	34.30	6,211.91
P3	1991	19.91	10,380	9.25	365	36.50	6,720.40
P3	1981	19.81	2,747	7.92	344	34.40	5,396.01
P3	1987	19.87	4,018	8.30	350	35.00	5,771.22
P3	1988	19.88	11,950	9.39	344	34.40	6,420.52
P3	1976	19.76	5,559	8.62	350	35.00	5,963.79
P3	1984	19.84	1,152	7.05	528	52.80	7,384.46
P3	1977	19.77	56,514	10.94	446	44.60	9,648.24
P3	1993	19.93	111,419	11.62	341	34.10	7,897.82
P3	1970	19.70	44,937	10.71	406	40.60	8,568.49
P3	1979	19.79	12,000	9.39	319	31.90	5,929.60
P3	1908	19.08	11,420	9.34	350	35.00	6,239.34
P3	1989	19.89	27,349	10.22	386	38.60	7,843.71
P3	2003	20.03	58,978	10.98	341	34.10	7,502.95

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P3	1993	19.93	5,000	8.52	353	35.30	5,992.09
P3	1988	19.88	27,120	10.21	353	35.30	7,163.63
P3	1994	19.94	13,528	9.51	318	31.80	6,031.81
P3	1994	19.94	9,436	9.15	308	30.80	5,620.90
P3	1995	19.95	2,966	7.99	349	34.90	5,566.54
P3	1952	19.52	3,849	8.26	528	52.80	8,508.65
P3	2003	20.03	10,925	9.30	386	38.60	7,189.45
P3	1984	19.84	6,672	8.81	337	33.70	5,887.54
P3	1948	19.48	7,178	8.88	353	35.30	6,105.44
P3	1986	19.86	10,884	9.30	406	40.60	7,494.75
H	1950	19.50	3,064	8.03	495	49.50	7,748.52
H	1998	19.98	2,924	7.98	495	49.50	7,893.00

Table G.4 Researcher D

Index Data Calculation Summary

Comparable Index		
MIN n=71	MAX n=71	MEDIAN n=71
4,297.29	16,551.36	7,648.89

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
H	1925	19.25	30750	10.33	495	49.50	9846.67
H	1916	19.16	557414	13.23	495	49.50	12548.61
H	1959	19.59	4800	8.48	495	49.50	8219.58
H	1943	19.43	21624	9.98	495	49.50	9600.11
H	1943	19.43	600	6.40	495	49.50	6152.47
H	1993	19.93	87074	11.37	495	49.50	11221.36
H	1997	19.97	3120	8.05	495	49.50	7953.18
P1	1910	19.10	3660	8.21	353	35.30	5532.20
P1	1927	19.27	15360	9.64	365	36.50	6780.01
P1	1914	19.14	20000	9.90	406	40.60	7695.84
P1	1941	19.41	540	6.29	406	40.60	4958.05
P1	1943	19.43	14460	9.58	407	40.70	7575.19
P2	1972	19.72	18624	9.83	494	49.40	9578.22
P2	1962	19.62	384	5.95	810	81.00	9456.88
P2	1975	19.75	13200	9.49	406	40.60	7607.93
P2	1977	19.77	16896	9.73	860	86.00	16551.36
P2	1963	19.63	5680	8.64	304	30.40	5158.75
P2	1964	19.64	2728	7.91	311	31.10	4832.27
P2	1965	19.65	1946	7.57	311	31.10	4628.30
P2	1964	19.64	729	6.59	705	70.50	9126.96
P2	1959	19.59	24000	10.09	406	40.60	8021.79
P2	1977	19.77	17920	9.79	406	40.60	7861.01
P2	1977	19.77	100	4.61	472	47.20	4297.29
P2	1968	19.68	75773	11.24	353	35.30	7805.34
P2	1979	19.79	2880	7.97	528	52.80	8323.29
P2	1979	19.79	8465	9.04	344	34.40	6156.73

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1918	19.18	111415	11.62	344	34.40	7667.45
P2	1938	19.38	7049	8.86	308	30.80	5288.95
P2	1953	19.53	3900	8.27	344	34.40	5555.20
P2	1973	19.73	6090	8.71	391	39.10	6722.67
P3	1991	19.91	68921	11.14	344	34.40	7630.32
P3	1982	19.82	1000	6.91	326	32.60	4463.32
P3	1986	19.86	3285	8.10	311	31.10	5001.15
P3	1981	19.81	8937	9.10	406	40.60	7317.36
P3	2001	20.01	176	5.17	529	52.90	5473.11
P3	1968	19.68	18270	9.81	528	52.80	10196.74
P3	1982	19.82	7200	8.88	365	36.50	6425.39
P3	1962	19.62	9140	9.12	309	30.90	5529.32
P3	2003	20.03	3200	8.07	344	34.40	5561.11
P3	1964	19.64	3717	8.22	353	35.30	5699.33
P3	1988	19.88	9600	9.17	528	52.80	9624.91
P3	1990	19.90	9300	9.14	483	48.30	8782.95
P3	1997	19.97	9600	9.17	428	42.80	7837.33
P3	1980	19.80	3727	8.22	304	30.40	4949.80
P3	1983	19.83	672	6.51	419	41.90	5409.22
P3	1959	19.59	3748	8.23	472	47.20	7608.91
P3	1951	19.51	2484	7.82	528	52.80	8053.15
P3	1988	19.88	16205	9.69	406	40.60	7823.55
P3	1970	19.70	11850	9.38	302	30.20	5580.59
P3	1999	19.99	48818	10.80	407	40.70	8783.43
P3	1986	19.86	12464	9.43	344	34.40	6442.83
P3	1987	19.87	1264	7.14	703	70.30	9976.43
P3	1999	19.99	5400	8.59	386	38.60	6631.37
P3	1999	19.99	54150	10.90	525	52.50	11438.77
P3	1987	19.87	13440	9.51	406	40.60	7668.69
P3	1996	19.96	576	6.36	365	36.50	4630.68
P3	2003	20.03	2889	7.97	349	34.90	5570.47
P3	1999	19.99	41218	10.63	407	40.70	8645.75
H	1974	19.74	2391	7.78	495	49.50	7601.55
H	1917	19.17	17845	9.79	495	49.50	9289.38
H	1942	19.42	24000	10.09	495	49.50	9695.39
H	1997	19.97	6028	8.70	495	49.50	8604.20
H	1969	19.69	19096	9.86	495	49.50	9607.40
H	1997	19.97	5200	8.56	495	49.50	8458.14

Table G.5 Researcher E

Index Data Calculation Summary

Comparable Index		
MIN n=43	**MAX n=43**	**MEDIAN n=43**
4105.34	17477.72	6269.75

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P1	1920	19.20	4660	8.45	309	30.90	5011.30
P1	1900	19.00	6038	8.71	309	30.90	5111.19
P1	1922	19.22	27600	10.23	338	33.80	6642.90
P1	1949	19.49	9600	9.17	406	40.60	7255.78
P2	1964	19.64	336330	12.73	344	34.40	8597.79
P2	1974	19.74	1210	7.10	705	70.50	9878.60
P2	1920	19.20	6763	8.82	380	38.00	6434.50
P2	1971	19.71	13849	9.54	365	36.50	6860.32
P2	1913	19.13	25256	10.14	365	36.50	7077.98
P2	1956	19.56	960	6.87	353	35.30	4741.40
P2	1966	19.66	3180	8.06	353	35.30	5596.84
P2	1966	19.66	6800	8.82	353	35.30	6124.31
P2	1961	19.61	396	5.98	350	35.00	4105.34
P2	1964	19.64	5952	8.69	551	55.10	9405.61
P2	1967	19.67	8774	9.08	494	49.40	8822.58
P2	1954	19.54	8104	9.00	348	34.80	6120.00
P2	1956	19.56	27400	10.22	406	40.60	8114.72
P2	1968	19.68	2487	7.82	494	49.40	7601.41
P2	1969	19.69	7900	8.97	344	34.40	6078.83
P2	1968	19.68	4232	8.35	406	40.60	6672.06
P2	1965	19.65	3456	8.15	353	35.30	5651.73
P2	1950	19.50	55229	10.92	323	32.30	6877.49
P2	1975	19.75	1920	7.56	353	35.30	5270.70
P2	1967	19.67	320	5.77	472	47.20	5355.45
P2	1960	19.60	1120	7.02	350	35.00	4816.46
P2	1961	19.61	7795	8.96	308	30.80	5412.48

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1971	19.71	30648	10.33	365	36.50	7431.79
P2	1950	19.50	5720	8.65	353	35.30	5955.41
P2	1931	19.31	6454	8.77	350	35.00	5928.86
P2	1925	19.25	1990	7.60	350	35.00	5117.73
P2	1966	19.66	10492	9.26	341	34.10	6206.87
P2	1910	19.10	29400	10.29	379	37.90	7447.92
P2	1957	19.57	2536	7.84	703	70.30	10783.77
P2	1926	19.26	8200	9.01	344	34.40	5970.77
P2	1979	19.79	3600	8.19	494	49.40	8005.48
P2	1960	19.60	5441	8.60	341	34.10	5749.04
P2	1960	19.60	400	5.99	406	40.60	4767.77
P2	1970	19.70	43615	10.68	424	42.40	8923.43
P2	1950	19.50	2750	7.92	406	40.60	6269.75
P2	1928	19.28	48006	10.78	841	84.10	17477.72
P3	1983	19.83	5700	8.65	528	52.80	9054.90
P3	1994	19.94	1300	7.17	386	38.60	5518.73
P3	1981	19.81	11600	9.36	353	35.30	6544.52

Table G.6 Researcher F

Index Data Calculation Summary

Comparable Index		
MIN n=29	**MAX n=29**	**MEDIAN n=29**
4126.77	8964.13	6108.86

Index Data Calculation

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P1	1950	19.50	11000	9.31	494	49.40	8964.13
P1	1948	19.48	3168	8.06	528	52.80	8290.94
P2	1976	19.76	24900	10.12	406	40.60	8120.94
P2	1978	19.78	26112	10.17	379	37.90	7624.18
P2	1968	19.68	8776	9.08	304	30.40	5432.18
P2	1970	19.70	173500	12.06	344	34.40	8175.49
P2	1979	19.79	32628	10.39	344	34.40	7075.25
P2	1969	19.69	3384	8.13	353	35.30	5648.60
P2	1963	19.63	9926	9.20	353	35.30	6377.06
P2	1971	19.71	3111	8.04	304	30.40	4819.06
P2	1956	19.56	352	5.86	470	47.00	5390.55
P2	1961	19.61	37843	10.54	309	30.90	6387.43
P2	1957	19.57	12320	9.42	484	48.40	8921.54
P2	1980	19.80	4032	8.30	366	36.60	6016.31
P2	1965	19.65	3000	8.01	344	34.40	5411.98
P2	1966	19.66	5472	8.61	311	31.10	5262.79
P2	1965	19.65	16319	9.70	344	34.40	6556.87
P2	1940	19.40	768	6.64	365	36.50	4704.47
P2	1900	19.00	384	5.95	365	36.50	4126.77
P2	1965	19.65	49404	10.81	406	40.60	8622.34
P2	1961	19.61	7608	8.94	365	36.50	6396.76
P2	1961	19.61	3993	8.29	344	34.40	5593.85
P2	1946	19.46	7280	8.89	353	35.30	6108.86
P2	1930	19.30	4213	8.35	353	35.30	5686.00
P2	1969	19.69	3776	8.24	407	40.70	6600.53
P2	1924	19.24	6532	8.78	353	35.30	5966.17

Data type	KCAO Year built	Yr Blt Index	KCAO Sq Ft	Log N Sq Ft Index	KCAO Predom Use Code	Predom Use Index	Comparable Index Totals
P2	1975	19.75	6984	8.85	309	30.90	5401.77
P2	1956	19.56	1595	7.37	344	34.40	4962.12
P2	1970	19.70	28490	10.26	344	34.40	6951.17

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APPENDIX H

KCAO DATA FOR PREVALANCE OF HEATING SYSTEM BY YEAR AND ASSOCIATED SQUARE FEET[19]

		1900-1952				
KCAO Heat Type Code	Description	N=	Median ft^2	Min ft^2	Max ft^2	Percent
3	Forced air unit	442	2,636	150	410,000	22.72
6	Space heaters	411	5,024	257	296,752	21.13
20	No heat	378	7,363	56	557,414	19.43
4	Hot water	217	8,976	374	205,000	11.16
0	None or Unknown	172	1,411	168	161,180	8.84
2	Electric wall	117	1,170	228	179,161	6.02
		1953-1980				
KCAO Heat Type Code	Description	N=	Median ft^2	Min ft^2	Max ft^2	Percent
3	Forced air unit	4,178	3,920	112	694,072	27.29
6	Space heaters	3,487	5,724	200	662,728	22.78
20	No heat	1,719	2,400	30	16,001,600	11.23
4	Hot water	1,384	10,832	336	1,236,136	9.04
2	Electric wall	1,005	2,272	128	71,343	6.56
12	Warmed / Cooled Air	883	8,565	27,042	1,038,000	5.77
14	Heat pump	845	6,689	247	776,762	5.52
		1981-2004				
KCAO Heat Type Code	Description	N=	Median ft^2	Min ft^2	Max ft^2	Percent
6	Space heaters	2,747	15,150	60	527,118	20.52
14	Heat pump	2,480	7,960	192	1,605,578	18.52
3	Forced air unit	2,023	5,664	104	342,484	15.11
12	Warmed / Cooled Air	1,513	14,707	224	1,952,220	11.30
20	No heat	1,008	3,200	60	1,846,950	7.53
0	None or Unknown	729	5,000	32	1,123,435	5.45
17	Complete HVAC	699	21,670	476	1,578,732	5.22

[19] Data represents heating systems with a $\geq$ 5 percent rate of occurrence.

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APPENDIX I
KCAO DATA FOR PREVALANCE OF HEATING SYSTEM, NUMBER OF BUILDINGS AND PERCENT SAMPLE POPULATION TOTAL

KCAO Heat Type Code	Description	Number of buildings	Percent Sample (n=30,642)
0	None or Unknown	1,455	4.7
1	Electric	1,067	3.5
2	Electric wall	1,613	5.3
3	Forced air unit	6,643	21.7
4	Hot water	1,884	6.1
5	Hot water radiant	90	0.3
6	Space heaters	6,645	21.7
7	Steam	293	1.0
8	Steam without boiler	183	0.6
9	Ventilation	26	0.08
10	Wall furnace	39	0.1
11	Package Unit	672	2.2
12	Warmed and Cooled Air	2,420	7.9
13	Hot and chilled water	109	0.4
14	Heat pump	3,335	10.8
15	Floor furnace	22	0.07
16	Thru-wall heat pump	4	0.01
17	Complete HVAC	816	2.7
18	Evaporative cooling	1	0.003
19	Refrigerated cooling	220	7.2
20	No heat	3,105	10.1

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APPENDIX J

RANDOM SAMPLES SURVEYED BY CITY AND VISIT QUALITY

Cities Surveyed n = 32	Total Samples n =	Useable Data n =	Unusable Data n =	Percent Sample %
Auburn	21	17	4	5.1
Bellevue	22	17	5	5.3
Black Diamond	5	5	0	1.2
Bothell	5	5	0	1.2
Burien	5	5	0	1.2
Carnation	4	3	1	1.0
Des Moines	8	5	3	1.9
Duvall	1	1	0	0.2
Enumclaw	7	6	1	1.7
Fall City	1	1	0	0.2
Federal Way	8	8	0	1.9
Issaquah	11	10	1	2.7
Kenmore	3	2	1	0.7
Kent	32	27	5	7.8
Kirkland	14	13	1	3.4
Lake Forest Park	1	1	0	0.2
Maple Valley	3	3	0	0.7
Medina	1	1	0	0.2
Newcastle	3	3	0	0.7
North Bend	5	4	1	1.2
Redmond	11	8	3	2.7
Renton	19	17	2	4.6
Sammamish	5	4	1	1.2
SeaTac	7	6	1	1.7
Seattle	155	132	23	37.6
Shoreline	14	13	1	3.4
Skykomish	3	0	3	0.7
Snoqualmie	5	3	2	1.2
Tukwila	5	4	1	1.2
Vashon	2	2	0	0.5
Unincorporated King County	16	11	5	3.9
Woodinville	10	9	1	2.4
Totals	**412**	**346**	**66**	100.0

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