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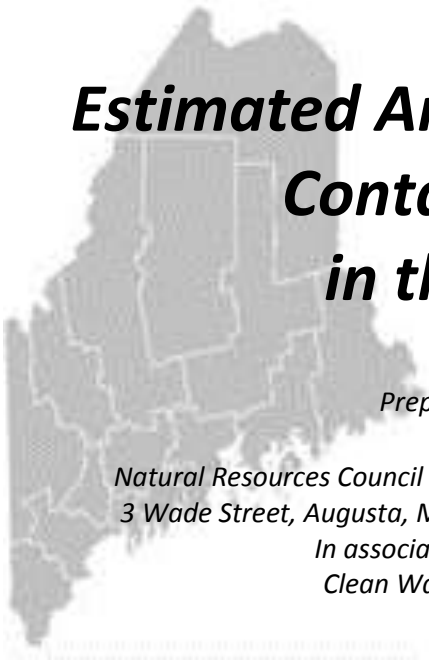

Estimated Annual Outflow of Mercury-Containing Thermostats in the State of Maine

Prepared for:

Natural Resources Council of Maine
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In association with
Clean Water Fund

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ORGANIZATION OF REPORT

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1. Project Background and Executive Summary

A number of states have enacted mandatory mercury thermostat collection laws that contain specific collection goals. However, little quantitative information is available on the number of mercury-containing thermostats currently in buildings or the expected flows of these devices out of buildings. As a consequence, some states have established goals using rules of thumb or simplistic assumptions. This study used primary field data to develop estimates of – and confidence intervals around – the values of interest.

Discussion of Maine Law

The State of Maine has had a disposal ban for mercury-added products since July 15, 2002. In 2004, the Maine Legislature enacted a prohibition on the sale of mercury-containing thermostats to begin January 1, 2006 (Maine Revised Statutes, Title 38, Chapter 16-B, at Section 1661-C.5), established collection goals for producers of mercury thermostats (Section 1666-B), and set out other definitions, regulations, and disclosure conditions related to the mercury thermostat collection program. The manufacturer responsibility portion of the law specifies elements of the collection program, including contractor collection bins (limiting fees), $5 minimum financial incentives for returns of mercury thermostats, and instituted reporting requirements by thermostat manufacturers. Wholesalers were also restricted from selling thermostats unless they established collection sites for mercury thermostats; other goals and requirements were also placed on wholesalers. The law also established non-enforceable goals for the collection program.[1] This study provides information to the State that can guide refinement of the goals, benchmark recovery levels achieved to date, and evaluate future collection efforts.

Summary of the Project's Steps

Under a contract to the Natural Resources Council of Maine (NRCM) and the Multi-State Mercury Products Campaign, the research and consulting firm Skumatz Economic Research Associates (SERA) of Superior, Colorado, developed a statistically-valid estimate of the mercury-containing thermostats that annually become waste in Maine.[2]

To develop the required estimates, SERA conducted the following project activities:

- Reviewed past work and the literature to develop and refine the technical approach for the project;
- Developed a web survey including the key questions needed to develop estimates to support the analysis;
- Designed appropriate sampling designs to "represent" the desired population, and purchased lists of random households, and stratified random sample of businesses, across the State;
- Prepared tailored postcards inviting the residential and commercial samples to complete the survey on-line (toll-free phone number also provided for those wishing to complete via phone);

[1] Additional information on the Maine law can be found at: http://legislature.maine.gov/statutes/38/title38sec1665-B.html
[2] This report represents the analysis and conclusions of SERA, not of the Natural Resources Council of Maine

- Mailed two rounds of postcards to the residential (single- and multi-family) sector and several rounds of postcards and email notifications to the commercial sector samples to improve the statistical properties and increase the response count;
- Analyzed the data gathered from the survey;
- Conducted interviews with thermostat experts and contractors (heating, ventilation, and air conditioning) in the region to gather information on mercury-containing thermostats in buildings to provide additional context for the data collected;
- Provided further validation of the data by gathering follow-up information from a sample of respondents, using photos of thermostats on-site to confirm counts and types of thermostats (96 camera validations representing 315 thermostats);
- Helped guide an effort to validate and provide additional context for the survey responses to be used in the analysis, which consisted of on-site visits to 46 respondent premises with 238 thermostats to verify accuracy of the survey responses on thermostat type and to provide inspection-based information on the presence of mercury in specific thermostat types (round, square, etc.)
- Prepared this report providing the study results and methods.

This report relies on surveys and statistical techniques to derive a defensible estimate of total annual mercury thermostat removals in the State of Maine, which may be used to advise the establishment of State goals for mercury thermostat recycling program performance. The study analyzed information from 892 survey responses about thermostats in the State, and the estimates show more than 1.8 million thermostats in place in Maine (more than 630,000 with mercury). With 4 grams of mercury each[3], wall thermostats currently in place in Maine buildings contain 2.5 metric tons of mercury. The number of mercury-containing thermostats flowing out of residential and commercial buildings in the state is approximately 16,000 annually for each of the next ten years. Figure 1.1 provides a summary of the estimate of mercury- and non-mercury-containing thermostats currently on walls in the State of Maine.

Figure 1.1: Summary Statistics of Thermostat Results for Maine

Summary Results	Residential	Commercial	Total
Number of Households or Establishments (thousands, from Census)	721.0	40.1	761.1
Average Thermostats per Unit	2.08	8.08	2.40
Number of Thermostats in place (thousands)	1,501.2	324.2	1,825.4
Percent of In-Building Thermostats Containing Mercury	37%	23%	35%
Estimated Number of Mercury-Containing Thermostats in Place (thousands)	554.8	75.3	630.2

Figure 1.2 presents the summary of the estimated flow of thermostats off walls in the State of Maine in ten year groups.

[3] http://www.newmoa.org/prevention/mercury/imerc/factsheets/thermostats_2014.pdf. *IMERC Fact Sheet Mercury Use in Thermostats, NEWMOA, January 2014.*

Figure 1.2: Estimated Ten Year Averages of Annual Outflows of Mercury-Containing Thermostats from Maine

Years	Mercury-Thermostats – Average Flow / Year for State of Maine	Mercury Thermostats: Cumulative Percent Flowed Out
2015-2024	16,000	25%
2025-2034	14,000	48%
2035-2044	12,000	67%
2045-2054	12,000	86%
2055-2064	8,000	98%
2065 on	2,000	100%
Total	630,000	100%

As Figure 1.2 indicates, it will take until about 2035 for one-half of the mercury-containing thermostats still in place to be removed from buildings in the State.

The figures presented in this report are conservative, because:

- Reasonably conservative assumptions about the percent of various types of thermostats that contain mercury were incorporated into the calculations;
- An adjustment factor (increase of 10%) correcting for under-reporting of potentially mercury-containing models was not incorporated; and
- We exclude thermostats in common areas of apartment buildings and some commercial buildings.

Background on the Literature

A detailed literature review was conducted to identify the best approach for conducting the analysis and identifying quantitative estimates of thermostat counts and flows. Three studies are presented below; the approach we selected is described in more detail in the next section. A more detailed review of the literature is provided in Appendix A.

- King County WA sent professional staff to a sample of businesses and counted thermostats; they found the number of thermostats in the non-residential sector varied with year built, remodel year, square feet, and dominant building use. This project tested the performance of on-site inspection as a means of conducting studies of this type.

- The next work was conducted by SERA on California residential and commercial thermostats – using surveys of businesses and households on existing and removed thermostats by type, along with statistical models, to develop estimates of inventories of mercury thermostats in place, measure lifetimes, and projected flows of removals of mercury vs. non-mercury models. The study was commissioned (by the Thermostat Recycling Corporation) to meet State requirements that the industry propose a methodological approach to estimating thermostat flows.

- In 2010, the Product Stewardship Institute tested two approaches. It used Frost and Sullivan national sales data-based estimates of thermostat turnover, and scaled the figures (using population) to develop estimates of the number of thermostats in the replacement market (thus, representing one estimate of the potential of thermostats flowing out). This did not answer the question of how many contained mercury. They tested two approaches for contractor surveys to gather information on the percent of wall thermostats that contained mercury, but found that response rates from contractors, even with backing from industry associations, were problematic, and the pilot project was not able to find an inexpensive approach to address that part of the question.

Summary of the Approach Used in This Study

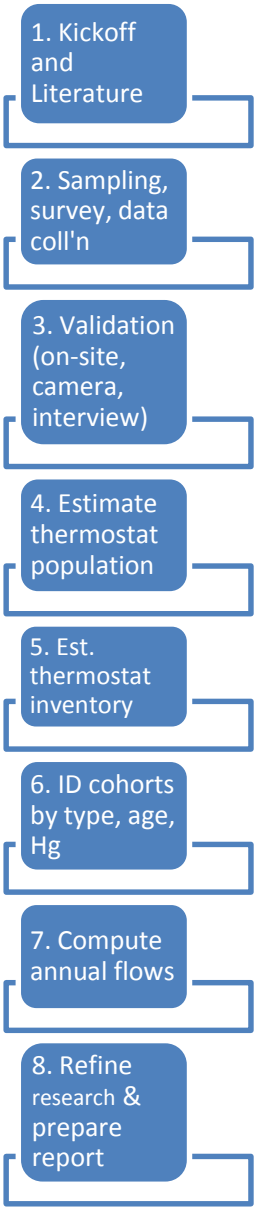
For the Maine study, we conducted a multi-step analysis very similar to work conducted concerning thermostats in Illinois, and Rhode Island, and with core similarities to the California DTSC study that was used as the basis for thermostat recycling goals adopted and implemented in legislation in the State of California. This Maine study also incorporated improvements and revisions reflecting peer reviews from the existing literature. The analysis consisted of the following steps, illustrated in Figure 1.3.

- **Data collection**: Send surveys to an appropriate random sample of homes, and stratified random sample of businesses in the state to ask about the number and types of thermostats in place, and information on ages and removals, and background information useful to assessing the statistical quality of responses.[4] Include first and second-round (follow-up) surveys, including web and phone responses.

- **Validation and research efforts**: Conduct in-field validation and research work, including three efforts. First, because it was not considered practical to ask households or businesses to open and inspect their thermostats for mercury, we sent trained staff (from a non-profit firm) to a random number of returned survey locations to validate the reported count and type, and to open and inspect whether the thermostats in place contain mercury, and determine potential age / other information (this effort was conducted by the Natural Resources Council of Maine, with SERA providing the sample to be surveyed). Second, a validation effort was conducted by phone and email, requesting a random sample of respondents statewide to send photos of all thermostats in place in to verify the "count" and types of thermostats compared to survey responses. Third, interviews were conducted with a sample of Maine and New England HVAC contractors in order to better understand thermostat installation and removal practices (current and historical), and suggest estimates of the percent of thermostats eligible for removal that contain mercury or not. This validation work provided additional sources of information for the inputs used in the computations.

[4] Note that the survey was presented or distributed to the sample as a 'thermostat survey". This differs from the approach taken in Illinois and Rhode Island, which were portrayed as "recycling and hard to recycle" surveys to try to increase response and encourage responses even from those with no thermostats. However, this "hard to recycle" approach increased the survey's length, and we opted for a more direct survey for Maine. It was suggested that Maine residents had a fairly high degree of interest in water and environmental quality, and this was the "hook" used to attract responses.

Figure 1.3: Summary of Research Steps



- **Estimate Measure Lifetime or Decay Curve**: From survey data on ages and removals of thermostats in residential and commercial buildings, use appropriate statistical techniques (hazard functions) that are commonly used to estimate lifetimes of energy-using appliances and equipment to estimate the expected measure lifetimes (expressed as median expected or effective useful life / EUL) of thermostats and the associated "decay" or removal distribution (percent over time, mapped against years after installation).

- **Compute Existing Thermostat Population on Walls**: Use survey data to estimate the average number of thermostats in place in residences[5], and multiply by the number of residences to compute the total number of residential thermostats in homes. Use appropriate sample weights to compute the total number of thermostats in commercial buildings. This is the total number of thermostats that are, essentially, "available" to be removed / recycled / disposed over time.[6]

- **Identify Cohorts by Thermostat Type**: For each type of thermostat in place in the State, compute the total number of each type of thermostat in place, and average age and age distribution of the remaining cohort of each thermostat type that is currently in place on walls across the State.

- **Estimate Annual Outflows of Mercury-Containing Thermostats**: Compute the total number of mercury-containing thermostats on walls by multiplying the total thermostats by type, times the percent of each type that contain mercury. Use the lifetime / decay curve to estimate the distribution of remaining lifetimes by thermostat type, accounting for their age cohorts, and compute the flow of mercury-containing thermostats available to be recycled annually into the future.

Each step of the research provides a key part of the calculation:

- A: Inventory or "count" of thermostats in place and available for removal and / or recycling: from the web survey (weighted appropriately), with corrections as needed (in count and type) from the on-site and camera validation work.
- B: Percent of the thermostat inventory in place in buildings that contain mercury: from the in-field validation work by NRCM, augmented with input from the contractors.

[5] *Including buildings with zero thermostats.*
[6] *The computation of the percent that are mercury takes place in a later step in this discussion.*

- C: Lifetime and decay function of thermostats in the field: from statistical analysis of survey responses on operating years of thermostats still operating and those that have been removed.
- D: Age distribution, and resulting outflow of the mercury-containing thermostat inventory in place in the field: from survey responses providing estimates of the year that existing cohorts of mercury-containing thermostats were installed. These figures are applied to the life decay function, resulting in estimates of mercury-containing thermostats "aging out" of buildings in the State.

The logic of the estimation work is summarized as follows:

A times B (resulting in the number of mercury-containing thermostats currently in buildings) have a distribution of ages (D), which can be expected to come out of service according to a decay function (expected useful life distribution, C). This is our flow of thermostats available for recycling.

One additional complexity was introduced in order to provide more refined estimates; however, the computation methods remain essentially the same. Rather than asking about "wall thermostats" in general, the survey and validation work asked about specific subgroups of thermostats. They are illustrated below, and comprise seven key types:

- Digital (any shape)
- Rectangular (not digital)
- Round (not digital)
- Snap (not digital)
- Pneumatic (not digital)
- Other non-digital
- Controls (not included)

This allowed us to incorporate known information about some types of thermostats, recognizing that the thermostats each represented a key technology at a point in time, and avoiding the answer "it depends" when speaking with contractors and others about how many thermostats had mercury. It also leveraged information and approaches by including similarities to the industry thermostat typology used in the SERA / DTSC / TRC studies that were conducted in California, Illinois, and Rhode Island. Refinements were made to clarify some types: square was replaced with the more correct "rectangular", and "not digital" was added to the names.

The results combine to provide an estimate of annual mercury-containing thermostat removals, which is key information needed for setting goals for recycling and informing program development in the State.

We developed this approach after reviewing alternatives available in the literature and associated peer review comments, and conducting an assessment of the strengths and weaknesses of the alternatives, relative to reasonable budget constraints.[7] The approach used for the State is a strong, well-grounded, and defensible approach, developed in a study that can be cited. The study's estimates provide good performance demonstrated in the confidence intervals and "fit" statistics for the model, as outlined below. In addition, the approach has the distinction of being used as the basis for setting regulatory thermostat recycling goals in the State of California. Evaluation is designed to provide information to guide better decision-making. The estimates developed in this study are defensible and support program design and goal-setting applications; the sample sizes were strong, and the study provides a quality basis for decision-making.

[7] *On-site work can cost 7-50 times the cost of surveys; it would be prohibitively expensive to acquire as large a sample as we obtained (and as many failures / change-outs as were noted) using purely on-site methods.*

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2. Conducting Steps A & B: Deriving an Estimated Inventory / "Count" of Mercury-Containing Thermostats in Maine Buildings

Population and Sample: The survey was based on a purchased sample.[8] We define three sectors: single family, multifamily, and commercial. To represent the residential sector, random samples of residential and multi-family addresses across the State were purchased. Our implicit assumption was that single-family homes were fairly homogeneous, and there was no particular reason, *a priori*, to assume that there were systematic differences in the lifetimes of thermostats in place in single family homes around the State[9]; therefore, a random sample would be appropriate. Similarly, we assumed a random sample of multifamily homes (apartments) could be used to represent multifamily responses statewide. The purchased samples were not proportional between these two groups. Because we expected lower response rates from multifamily homes, we purchased a larger-than-proportional sample from these households to obtain sufficient responses. Then the responses from these two groups were weighted based on their ratio within the underlying population to properly represent the "overall residential" results for the State for the analytical work.

To represent the commercial sector, a stratified random sample design was selected. To recognize the complexity and potential differentiation within the commercial sector, we stratified on classes based on the number of employees at the establishment. There are a large number of small businesses, and they are likely to be relatively homogeneous, and similar to each other in size, as well as number and lifetimes of thermostats. However, they may be expected to differ from larger firms, at least in the number of thermostats they have. We were able to stratify on employment size at the site, which we used as a proxy for square footage or size, a variable we *did* expect to have an effect on at least the number of thermostats at the sites. We intentionally did not purchase proportional samples for each commercial strata (in accordance with standard statistical literature, including Cochran, Dillman, and others[10]) because:

1) we anticipated differential (higher / lower) response rates for some strata, and a proportional sample would not include enough of this population to provide enough responses. To counter for that, we needed to purchase higher or lower-than-proportional samples for individual strata;
2) we expected greater variation in numbers of thermostats within some strata than others[11] and precision gains are realized when heterogeneous populations are divided into more homogenous subpopulations (this typically means that the strata have substantially different means, variances, or both); and

[8] Purchased from InfoUSA, a well-known vendor.

[9] Or, if there were, we would uncover it as part of the work; it was not something known ahead of time in a way that would support complex residential sampling. In energy end-use surveys, the residential sector is rarely stratified beyond single- vs. multi-family.

[10] Cochran, W. G.. 1977. Sampling Techniques. John Wiley & Sons, New York; Dillman, DA, Smyth J, and Christian, L, "Internet, Mail, and Mixed Mode Surveys: The Tailored Design Method". Third Edition. Hoboken NJ, John Wiley and Sons, and earlier versions.

[11] Based on size of facility at least, reflected in employment.

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3) stratification may contribute to avoiding estimation bias, depending on the estimator selected.

These conditions argue for stratified sampling, and stratified sampling is a statistically efficient approach for this sector. The stratified approach ensures the overall responses are more representative of the entire population. The standard foundation literature on this topic remains the widely cited seminal work by Cochran (1977), Dalenius and Hodges (1959), among others.[12] Confidence intervals can be narrowed appreciably with appropriate stratification, and this is the approach used in the SERA study.

We purchased a random sample of each of three business sizes or strata (very small, small to medium, and large / very large, defined as 1-4 employees, 5-99 employees, and 100 and more). There are thousands of the smallest ones, and they become progressively less numerous as the employment categories increase. We traditionally purchase increasing *proportions* (not numbers) of sample from the larger firms so we could be reasonably certain the population in that group would be represented by multiple respondents. In Maine, we actually purchased all of the names for the larger business categories. This stratification technique can improve the quality and robustness of the data.[13] The analyses then appropriately applied post-sample weights to the data from the strata to account for variations in the sampling proportions and response rates.[14]

Figure 2.2 later in this chapter shows the sample sizes, response rates, and estimated "counts".

Survey Approach: There were at least two rounds of contact for each sampled group. Households received a postcard, with a follow-up postcard to a sample of the non-respondents. Very small and small / medium businesses received a postcard, emails, and follow-up phone calls to a sample of the non-respondents. Larger businesses received emails and multiple rounds of phone follow-ups to non-respondents.

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[12] Cochran, W. G.. 1977. Sampling Techniques. John Wiley & Sons, New York.; Dalenius, T., J.L. Hodges, 1959. Minimum Variance Stratification. Journal of the American Statistical Association, 54, 88—101. The following are relevant quotations from citations. Cochran, William, Sampling Techniques, Third Edition, John Wiley & Sons 1977, p. 99: "If intelligently used, stratification nearly always results in a smaller variance for the estimated mean or total than is given by a comparable simple random sample." Kish, Leslie, Survey Sampling, Second Edition, John Wiley & Sons 1995, p 76 states "Stratification may be used to decrease the variances of the sample estimates. In proportionate sampling, the sample size selected from each stratum is made proportionate to the population size of the stratum. The variance is decreased to the degree that the stratum means diverge and that homogeneity exists within strata. On the contrary, in disproportionate or optimal allocation, different sampling rates are used deliberately in the different strata. The variance (per unit cost) can be decreased by increasing the sampling fractions in strata having higher variation or lower sampling cost." Valliant, Richard, Jill A. Dever, and Frauke Kreuter, Practical Tools for Designing and Weighting Survey Samples, Springer, 2013, page 43: "Selecting a simple random sample runs the risk that one or more important domains will be poorly represented or omitted entirely. In addition, variances of survey estimates can often be reduced by using a design that is not srswor (stratified random sampling without replacement). A design that remedies the problems noted for an srswor is referred to as stratified simple random sampling (without replacement) or stsrwor." Lohr, Sharon L., Sampling: Design and Analysis, Second Edition, Boston: Brooks/Cole 2010, p. 74: "If the variable we are interested in takes on different mean values in different subpopulations, we may be able to obtain more precise estimates of population quantities by taking a stratified random sample....Stratification works for lowering the variance because the variance within each stratum is often lower than the variance in the whole population."

[13] Stratified sampling is the norm in commercial sector surveying, and improves the efficiency of the survey – improving the quality of resulting estimates from a given number of responses.

[14] If there are 1000 small businesses and we received responses from 100, each survey stands in for 10 businesses in this group. If there are 100 medium businesses and we got 30 responses, then we weight each response by a factor of 3.3, and then compute weighted averages for the entire sector using these kinds of weights.

The postcard and email outreach asking the sampled entities to complete the survey were mailed via postcard to the sampled homes and businesses, and the postcards and emails provided a link to a web survey (on SERA's neutral website "garbageandrecyclingsurvey.com"). The initial contact was followed up with two email follow-ups to the business sample. After the postcards were issued (two rounds to households; one to businesses, followed by email outreach) and responses had slowed, phone calls were initiated to single and multi-family homes as well. Both the postcards and emails also directed recipients to a toll-free number if they preferred to complete the survey by phone (which removes a barrier for elderly households).[15] The postcard and emails also notified recipients that filling out the survey entered them into a lottery to win one of several Kindles and gift cards[16]. Examples of the postcards and emails are provided in Appendix E. To complete the web survey, users visited the website and clicked on the labeled button to launch the survey. A web survey was selected because it provided several advantages.

- Drawings / pictures can be incorporated for clarification of issues – particularly identification of mercury- vs. non-mercury containing thermostat types;
- Respondents can complete the survey at their convenience (rather than only during phone hours, which helps accommodate small businesses),
- It can be distributed easily and relatively inexpensively, and the survey is fielded quickly,
- Skip patterns are automatic - so errors do not arise and the survey can be shorter or longer based on specific responses;
- Data are automatically entered into the computer – no separate keypunch entry costs (and errors.)
- On-going data checking – we can look at responses after the first few and make adjustments to the survey to correct for anything that seems unclear or to probe on issues; and the data can be analyzed in "real time" and the survey "left active" and analyzed again when more responses have been received.
- Responses can be limited to one per computer.

Questionnaire content: The questionnaire (or "survey instrument") collects the key analytical data of interest, as well as relevant demographics or "firm-o-graphics", which allows us to match back to the stratification and weighting strategy, and then compare response proportions against the initial database or against published "census" or other data. The questionnaire is included in the Appendix. The key analytical information solicited in the questionnaire included:

- Whether there are any wall[17] thermostats in buildings.
- Type of thermostats (we included photos of various types, and asked respondents to classify thermostats into digital, rectangular (not digital), round, snap, pneumatic, other (or controls), as shown in the photo in the executive summary).
- How many wall thermostats in buildings of the type(s) of interest; whether each is still functioning (&)[18]
- Year built (*); best estimate of year thermostats were installed, and, if any were removed, when removed(&).

[15] On the phone surveys, the thermostat types were able to be unambiguously described by shape, without photos.

[16] We have found this prize works well for both the residential and commercial sector. The cost of even several dozen Kindle players is still many times less than the cost of a large scale phone survey.

[17] The questions were designed to gather information on wall thermostats, excluding baseboard and pneumatic thermostats which tend not to contain mercury.

[18] The features marked with asterisks (*) were identified as strong explanatory factors for the King County work. The data collection elements marked with ampersands (&) represent those needed to support measure retention / removal analyses.

- Demographic data: type of home (SF detached, attached, MF, etc.); number of residents, square footage, number of bed and bath rooms (predictor for square footage); education of head of household.
- Firmographic data: estimated square footage, number of employees.
- Locational data: County and zip.

Information on number of thermostats, by type, is all that is needed to establish "A", the inventory. The questions on age and failures are needed to support the work in "C" and "D".

Sample Sizes and Confidence: Statistical computations allow the researcher to estimate the number of responses needed to achieve a certain confidence level associated with the resulting estimates. The table below provides the number of responses needed to reach precision and confidence thresholds, depending on the size of the underlying "population". The number of responses needed to represent a city of 10,000 and a state of 10,000,000 at +/-5% accuracy with 95% confidence[19] is not very different. No matter how big the total households (within a fairly large band), the sample sizes needed are similar.[20]

Getting sufficient respondents can be expensive, and depend on the number mailed out and the response rate. Response rates are lower if the surveying entity does not have a relationship with the sample (e.g. utility companies will get higher response rates with program participants than research firms will get with random digit dialing techniques). However, the samples sizes for EUL surveys are even more difficult, because , although general responses are satisfactory for the inventory portion of the project, to estimate lifetimes and turnover, you need responses related to "failures and removals", which happen in (or are known about in) only a portion of the responding businesses and homes. Larger mail-outs and samples are needed to represent these changes. We obtained more samples to assure we have enough that failed / were removed. Generally, however, more data (rather than less) will tend to help any predictive modeling work.

Figure 2.1: Computation of Sample Sizes and Resulting Accuracy / Confidence in Responses

IF the community's population (homes or com'l bldgs) is…	95% Confidence		90% Confidence	
Computed responses needed for accuracy of…	+/-5%	+/-10%	+/-5%	+/-10%
100	79	49	73	40
1,000	278	88	213	63
10,000	370	95	263	67
100,000	383	96	270	68
1,000,000	384	96	271	68
10,000,000	384	96	271	68

The usual benchmarks for strong responses are +/-5% or 10% at the 90 and 95% confidence level; this translates to approximately 68, 96, 270, or 368 survey responses to provide the respective benchmarks.

[19] The statement of confidence level is standard practice; however, it is simplified and slightly misleading. It states the accuracy with which you would predict a 50% response (e.g. male / female, yes/no) given random responses totaling the number given from the sample, compared to the answer from the population. It does not predict the accuracy of an answer of, say, "9" from among a number of categories, etc. However, it serves as a much-used industry-standard benchmark for higher vs. lower accuracy sample sizes.

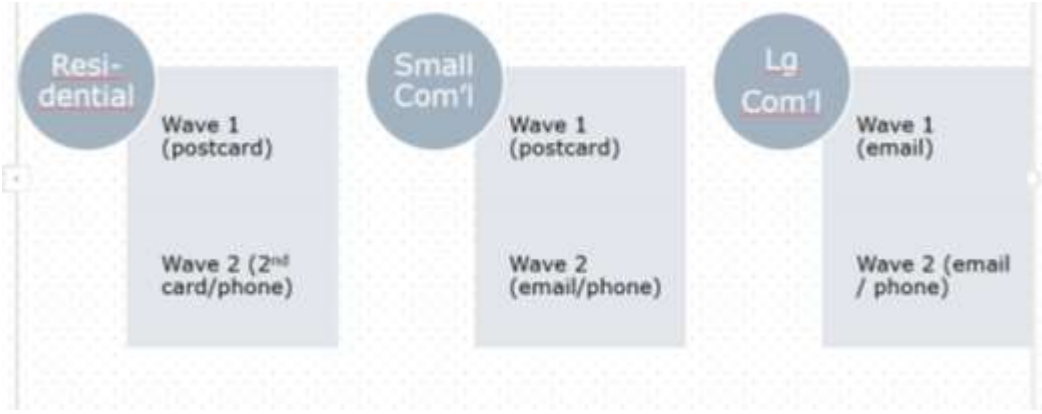
[20] This is why Nielsen television ratings or Gallup election polls can use nationwide samples of 1200 and get accuracy nationwide.

Response Rates Achieved in Maine: The Maine survey responses received – 612 residential (with thermostat data) and 280 commercial – provides accuracy levels of, respectively, +/-4.0% and 5.8% at the 95%[21] confidence level. These response counts are within the level usually considered strong for analytical work of this type.

Several techniques were used to increase the response rates. One technique was the option for respondents to enter a drawing for a prize. The literature is somewhat divided on the effectiveness of incentives to promote survey responses, and academic, scholarly, and governmental publications continue to discuss pros and cons of use and types of incentives.[22] We used a hybrid approach – entry into a drawing with an "opt-out" for those who don't want prizes.

A second technique, and one that is a basic tenet of survey work, is conducting follow-up or multiple rounds of outreach for surveys. We conducted an initial round of postcards, followed by a postcard to a sample of non-respondents and additional phone outreach to a sample of non-respondents for the single- and multi-family sectors. The commercial sector received either postcard followed by two email rounds and phone follow-up to samples of non-respondents (very small and small / medium), or email, with phone follow-up to a sample of non-respondents for the large businesses.

Figure 2.2 Maine Survey Waves – Initial Outreach and Follow-up Approaches



[21] Also equals +/- 3.3 and +/-4.9% at 90% confidence level, respectively.

[22] Regarding the use of incentives, the literature is divided on the effectiveness of incentives, and academic, scholarly, and governmental publications continue to discuss pros and cons of use and types of incentives (Dillman, CDC / Centers for Disease Control and Prevention, Joint Statistical Meetings, NIH, and others). Therefore, we used a hybrid approach – entry into a drawing with an "opt-out" for those who don't want prizes. A review of sources is summarized as follows. Dillman, DA, Smyth J, and Christian, L, "Internet, Mail, and Mixed Mode Surveys: The tailored Design Method". Third Edition. Hoboken NJ, John Wiley and Sons addresses three factors affecting response rates – trust, effort, and reward (and the structures of rewards); CDC Evaluation Brief #22 July 2010 "Using Incentives for Boost Response Rates", addressing pros and cons of options; Kaplan Aljoshca and Glenn White, 2002. "Incentives in a Business Survey: a Study in Improving Response Rates". Joint Statistical Meetings – Section on Survey Research Methods: 1756-1761; Council of Professional Associations on Federal Statistics (COPAFS) "Incentive Conference Session II: Use of Incentives – Who, What, Where, When, Why, and How", 2012; Singer, Eleanor, and Mick P. Couper, "Do Incentives Exert Undue Influence on Survey Participation? Experimental Evidence" (which concludes research 20 years ago leaned away from incentives, but that falling response rates from non-cooperation, not non-contact, has led to a revisiting of the issue); National Institutes of Health Public Access, Journal of Empirical Research Human Research Ethics, September 2008, 49-56; National Business Research Institute (NBRII.com), "Survey Incentives: Response Rates and Data Quality", website, undated.

A response follow-up analysis was conducted for each customer group. Average thermostat figures were compared for households and businesses responding to the first wave of outreach, and those responding to the follow-up wave of outreach. In each case, the computed values for average thermostats were not statistically significantly different at the 90% or 95% confidence levels for the data collected in the first outreach vs. follow-up rounds. As a consequence, no special weighting for outreach waves was invoked.

To confirm that the responses received were reasonably representative of the state, we compared response rates by county to census data (see Appendix B), and found no significant evidence of bias; responses were received from across the state in proportions generally representative of census frequencies.

We estimated the "average" number of thermostats for each respondent type, as shown in Figure 2.3 (single family, multifamily, and the commercial strata).[23] To develop estimates for the subtotals and total (residential, commercial, total), we used census "population" figures times the average thermostats per unit to estimate the total thermostats on walls in the State of Maine. These are the raw survey-based computations. Additional field and camera validation work was conducted to allow us to adjust the results based on possible sources of respondent error (counts and types of thermostats), and we also use field data to identify the share of the total of these thermostats that contain mercury.

Figure 2.3: Sample Size, Responses, and Estimated "Count" of Thermostats on Maine Walls

Category	ME Sample Purchased	ME Responses with # Therm	95% & 90% Confidence Levels	Response Percent of Purchased Sample (not adjusted for bad addresses, etc.)
Single Family (SF) HHs	7,000	385	+/-5.0%; +/-4.2%	5.5%
Multi-family (MF) HHs	3,500	227	+/-6.8%; +/-5.7%	6.5%
Businesses, very small	2,500	60		2.4%
Businesses, small / medium	8,500	181		2.1%
Businesses, large	870	39		4.5%
Residential Total	10,500	612	+/-4.0%; +/-3.3%	5.8%
Commercial Total	11,870	280	+/-5.8%; +/-4.9%	2.4%
Grand Total	22,370	892		4.0%

Figure 2.4: Computation of Estimated Inventory of Thermostats on Maine Walls

(note: pneumatics were reported for a small number of commercial buildings and are included)

Category	Census Units & Establishments	Number of Thermostats, Average by Class / Sector	Estimated Total Thermostats in ME Buildings (thousands)
Single Family (SF) HHs	582,841	2.23	1,299.0
Multi-family (MF) HHs, per unit	138,153	1.46	202.2
Businesses, empl <=19	20,865	2.15	44.9
Businesses, empl 20-99	11,998	7.17	86.0

[23] The survey contained two questions related to number of thermostats. In most cases, the total thermostats reported matched the responses derived from summing the number of thermostats by type. In cases where the surveys showed different numbers of thermostats, we used the sum of the number of thermostats of each type, because that question came later and was based on more detailed information.

Category	Census Units & Establishments	Number of Thermostats, Average by Class / Sector	Estimated Total Thermostats in ME Buildings (thousands)
Businesses, empl 100+	7,249	26.67	193.3
Residential Total	720,994	2.08	1,501.2
Commercial Total	40,112	8.08	324.2
Grand Total	761,106	2.40	1,825.4

To provide a context for the results from the Maine work, we benchmark the findings with the most comparable work available in the literature – the results from the 2009 California study (SERA 2009)[24], the Illinois study (SERA 2014)[25], and the Rhode Island study (SERA 2014).[26] The comparison in Figure 2.5 shows the averages and the "normalized" results (that is, the number of thermostats normalized to the population or size of the state) from these states are similar. The study estimates that there are 0.52 to 0.69 thermostats per capita in each state, with Rhode Island's totals about 16-33% higher per capita than the totals in Illinois and California, and Maine's figures about 1.37, a figure about twice as high as the other states. We also compared the available outflows of mercury-containing thermostats in each of the next 6 years for Illinois, California, and Rhode Island (and 5 years for Maine). The estimates are a similar order of magnitude – 85-108 in Rhode Island vs. 79 and 101 per 10,000 people in the other two states, and Maine's figures are a bit higher, at about 118 thermostats per 10,000 residents.

Figure 2.5: Comparison of Maine Results to Findings from Similar Studies in the States of Rhode Island, Illinois and California (SERA, 2014, 2014, 2009, respectively)

Comparison of Thermostat Inventory and Outflow Results	Maine (2015)	Rhode Island (2014)	Illinois (2013)	California (2009)
Average Number of Thermostats				
Per Household	2.08	1.23	1.15	1.17
Per Business	8.08	5.81	5.16	5.6
Overall (weighted average of households & businesses	2.40	1.49	1.38	1.5
Total Thermostats in State (thousands)	1,825	731	7,700	19,800
Mercury Thermostats (thousands)	630	258	1,864	5,100
Percent Thermostats on Walls with Mercury	35%	35%	24%	26%
State Population (thousands)	1,328	1,051	12,900	38,000
Thermostats per Capita (therm/pop)	1.37	0.69	0.6	0.52
Mercury Thermostats per Capita (therm/pop)	0.47	0.25	0.14	0.13
Comparison of Annual Outflow Estimates	Maine	Rhode Island	Illinois	California
Mercury Thermostats per Year, Average for 2015-2019	16,000[27]	8,900-11,400	102,000	199,700
Mercury Flow / Population * 10,000	118	85-108	79	101

[24] Skumatz, Lisa A., Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings- A Study to Meet Requirements for State of California Thermostat Recycling Legislation, Skumatz Economic Research Associates, Superior, CO, for TRC, December 28, 2009.

[25] Skumatz, Lisa A., Estimated Annual Outflow of Mercury-Containing Thermostats in the State of Illinois, Skumatz Economic Research Associates, Superior, CO, for NRDC, Multi-State Mercury Products Campaign, and Clean Water Fund, January 2014.

[26] Skumatz, Lisa A., Estimated Annual Outflow of Mercury-Containing Thermostats in the State of Rhode Island", Skumatz Economic Research Associates, Superior, CO, for NRDC, Multi-State Mercury Products Campaign, and Clean Water Fund, October 2014.

[27] 10 year average

Validation Efforts

Three validation efforts were conducted. All contribute to the computations of Steps "A and B" – identifying the "count" of thermostats by type, and the percent that contain mercury.

Validation 1 – On-site: The Natural Resources Council of Maine (NRCM) sent trained staff to complete on-site visits to a set of specially selected respondent buildings (residential and commercial). They completed on-sites at 46 survey respondent sites (residential and commercial), containing 238 thermostats.[28] Their trained staff verified the count of thermostats, and inspected the rectangular, round, and "other" thermostats to determine whether they contained mercury or not. They also checked whether the sample of survey respondents were accurate in their report of the number and type of thermostats in their home or establishment. NRCM staff photographed thermostats to document the presence of mercury in the thermostats. SERA provided the sample from among buildings that responded to the survey (residential and commercial, randomly selected within geographic clusters[29] to manage travel costs). The on-site staff were aggressive in their coverage of the State; they received cooperation from all but two counties in the State. These results provided valuable information to develop possible 'correction factors' to be applied to the averages and counts estimated from the survey data.

Validation 2 – Camera Phone: SERA contacted a random set of 96 respondents around the State (by phone and email) and asked them to take a digital photo of each "type" of thermostat they had, and re-count the number of thermostats on their walls.[30] In return, for those sending in photos, gift certificates to Best Buy, Starbucks, or Target (respondent's choice) were sent. The camera validations reconfirmed 315 thermostats. This sample included all types of thermostats. This supported a validation of the "count" against their response, and the types they reported as well. Again, this provided information on correction factors for the survey data.

Validation 3 – Contractor Interviews: SERA conducted detailed interviews with 18 New England area (including Maine) HVAC contractors. We asked about the different types of thermostats, their frequency in residential and commercial buildings, and about estimates of the percent of thermostats that contain mercury. These interviews provided extra information to inform the inputs used in the computations.

On-Site Validation Results – Percent of Thermostat Models Containing Mercury

Figure 2.6 tabulates the results of the on-site validations by NRCM regarding the percent of thermostats inspected that contained mercury. The samples sizes for the on-site mercury inspections are

[28] The on-site validation sample included buildings in all but two counties in the state, providing strong representation statewide.

[29] Some sampling preference for non-digital thermostats was introduced into the sample, as it was known that digital thermostats would not contain mercury, and the primary objective of the on-site surveys was to inspect for the presence of mercury. Validation of number and visual types was checked through the camera survey, providing additional confirmation on digital models.

[30] The camera validation allowed us to confirm classifications, and check the consistency of the count of thermostats on the walls.

moderately strong (at least on the commercial side).[31] We elected to use the proportions based on the number of those thermostat types in place and inspected in the residential and commercial sector.[32] When weighted by "type" based on the survey responses, the overall percent of mercury-containing thermostats on walls in Maine is estimated to be 35% (see Figure 2.8). When asked about the percent of all thermostats in place on walls that contained mercury, the (limited) sample of contractors reported that had a range of 4-50% overall, and our estimate is a little higher than the middle of that range.

Figure 2.6: On-Site Validation Results: Percent of Thermostats Containing Mercury, by Type

	Digital	Round	Rectangular	Snap	Pneu-matic	Other
Commercial - ME		100%	75%			0%
Residential - ME		89%	100%			0%
Number Inspected	0	27	52	0	0	2
Weighted by All Therms (82% res; 18% com'l) – ME		91%	96%			0%
Weighted by Therms by Type (about 85% of Hg therms in Res) - ME		91%	96%			0%
Weighted by "Units" (95% res / 5% com'l) – ME		89%	99%			0%
Simple Average – Maine data		94%	88%			0%
Rhode Island (Commercial/Residential)	0%/0%	96% / 100%	64% / 80%	0% / 0%		
Illinois (Commercial / Residential)	0%/0%	95% / 100%	70% / 100%	3% / na		9% / na

The results show that the only mercury-containing thermostats on Maine walls are of the round and square types (this is consistent with findings from other states). Based on these results, the total thermostats that are mercury-containing were estimated somewhat conservatively[33] using the figures found for residential and commercial mercury saturations from above:

- 100% of commercial, and 89% of round models are assumed to contain mercury;[34]
- 75% of commercial, and 100% of residential rectangular thermostats are assumed to contain mercury;
- 0% of other types of all other thermostat types are assumed to contain mercury;
- No thermostats installed since 2006 (less than 10 years old) are assumed to contain mercury.[35]

[31] These figures are consistent with results from a similar set of on-site inspections performed in Illinois and Rhode Island, which developed averages of 84% and 98% (IL) and 72% and 98% (RI) for percent of square and round thermostats with mercury. The Illinois work indicated there may be small percentages of snap and lever-type thermostats that have mercury as well (1.5% and 4.5%). Weighted averages, by type, were 94%, 99%, 1%, and 2% (IL). The figures used for Maine are conservative. The Illinois sample size was a total of 289 thermostats inspected, and 138 inspected in Rhode Island. A total of 81 were inspected for mercury in Maine. (Skumatz, "Annual Outflow of Mercury-Containing Thermostats in Illinois", prepared for NRDC, 2014; Skumatz, "Annual Outflow of Mercury-Containing Thermostats in Rhode Island", prepared for NRDC, 2014).

[32] This parallels the conservative approach used for previous work in Illinois (SERA 2014); in that study, estimates of 70% for square and 95% for round were used to represent the mercury share of these thermostat types. In Rhode Island, proportions of 72% and 98% respectively, were used.

[33] Note that the estimates of total potential mercury-containing thermostats are reduced by the omission of thermostats located in common areas of multi-family buildings. It was not considered feasible to ask residents in these buildings to inspect the hallways and common areas outside their unit.

[34] Using 89% for the residential factor is a conservative assumption because it is a relatively lower proportion attached to the vast majority of the thermostats.

[35] Based on legislation.

Validation Findings on Survey Counts

Figure 2.7 compares the total number of thermostats that a sample of business and household respondents provided on the survey to thermostat counts validated using on-site and camera re-count methods. The results show that the total counts from the validation work were very close to those reported in the survey; they reported approximately 2% too many thermostats overall. In the past, households tended to include some other equipment in their count (including controllers for fans or air conditioners), so we separately accounted for these units in the survey, and the accuracy in counts for the remaining thermostats was strong.

Figure 2.7: Validation Results on Total Count of Thermostats, Total and by Thermostat Type

	Residential	Commercial	Combined, weighted
Number of thermostats reported by survey	241	312	
Number of thermostats found in on-site and camera validations	239	289	
Resulting "adjustment" factor for totals (combined is weighted by prevalence of residential vs. commercial)	99%	93%	98%

We also reviewed the on-site and camera feedback on the accuracy of reports on the types of thermostats in place, and checked whether any inaccuracies affected the estimated total of mercury vs. non-mercury-containing thermostats. There were some mis-classifications among the residential and commercial installations validated. The overall effect (Figure 2.8) suggests that the mis-assignment of mercury thermostat types could justify an increase of about 10% for the estimate of mercury-containing models. The validation survey uncovered a 10% under-reporting of mercury-type thermostats, but work on the age distribution of thermostats implies about 10% of the mercury types were reported as less than 10 years old. In general, this represents a “wash” in the counts. Given this strength in performance, we elected not to modify the thermostat counts reported in the study (see Figure 2.7 below). The combinations of adjustments are addressed in the corrected totals in Figure 2.10. Graphics of the survey responses on types of thermostats in residential and commercial buildings in Maine are presented in Figure 2.11.

Figure 2.8: Validation Results on Total Count of Thermostats, Total and by Thermostat Type

	Total
Total number of mercury-containing thermostats reported from validation sample's on-line survey & interviews	238
Number of mercury-containing thermostats from camera and on-site validation, same sample	262
Resulting potential "adjustment" factor for totals (validated / survey)	110%

Figure 2.9: Calculation of Inventory of Mercury-Containing Thermostats in Buildings in Maine, absent correction factors

Percent by Thermostat and Building Types, pre-Adjustment	Digital	Rect-angular	Round	Snap	Pneu-matic	Other	Est Pct with Mercury	Mercury Thermo-stats (thous)	Total Thermo-stats (thous)
SF HHs (Grp1)	61%	9%	30%	0%	0%	0%	36%	464	1,299
MF HHs (2)	51%	12%	37%	0%	0%	0%	45%	91	202
Res Total	59%	10%	31%	0%	0%	0%	37%	555	1,501
Com'l Total	54%	7%	30%	0%	0%	1%	23%	75	324
Grand Total	58%	9%	31%	0%	0%	0%	35%	630	1,825
Residential Total (thous)	887.0	149.6	464.5	0.0	0.0	0.0			
Commercial Total (thous)	175.4	23.0	95.8	0.0	0.0	2.4			
Grand Total (thousands)	1,062.5	172.6	560.3	0.0	0.0	2.4			
Percent with Mercury (Fig.2.5; commercial)	0%	75%	100%	0%	0%	0%			
Percent with Mercury (Figure 2.5 residential)	0%	100%	89%	0%	0%	0%			

Figure 2.10: Adjustments to Mercury Thermostat Counts, and Revised Total, Maine (thousands)

Potential Adjustments	Initial (Figure 2.9)	Mis-reporting Total Number of Thermostats vs. Validation; 98% (Fig 2.7)	Under-report Mercury-Containing Types; add 10% (Fig. 2.8)	Re-classify Reported Hg Thermostat Less than 10 Years Old (~10%)	Revised Totals
Estimated Mercury-Containing Thermostats (Figure 2.8)	630.2	617.6	693.7	567.2	630.2
Estimated Non-Mercury Thermostats	1,195.2	1,171.4	1,131.7	1,194.7	1,195.2
Estimated Total Thermostats	1,825.4	1,789.0	1,825.4	1,761.9	1,825.4
Mercury Percent of Total	35%	35%	38%	32%	35%
Decision	Base Figure	Not invoked; small adjustment	Not invoked because balances with next factor for Hg therms	Not invoked because balances with previous factor for Hg therms	Original

Figure 2.11: Revised Thermostat Counts, after Selected Correction Factor from Figure 2.9 is Applied

Percent with and without mercury by Building Type, adjusted	Percent of T-Stats with Mercury	Number of Mercury-Containing T-Stats	Total Thermostats
SF HHs (Grp1)	36%	463,900	1,299,000
MF HHs (2)	45%	91,000	202,200
Res Total	37%	554,800	1,501,200
Com'l Total	23%	75,300	324,200
Grand Total	35%	630,200	1,825,400

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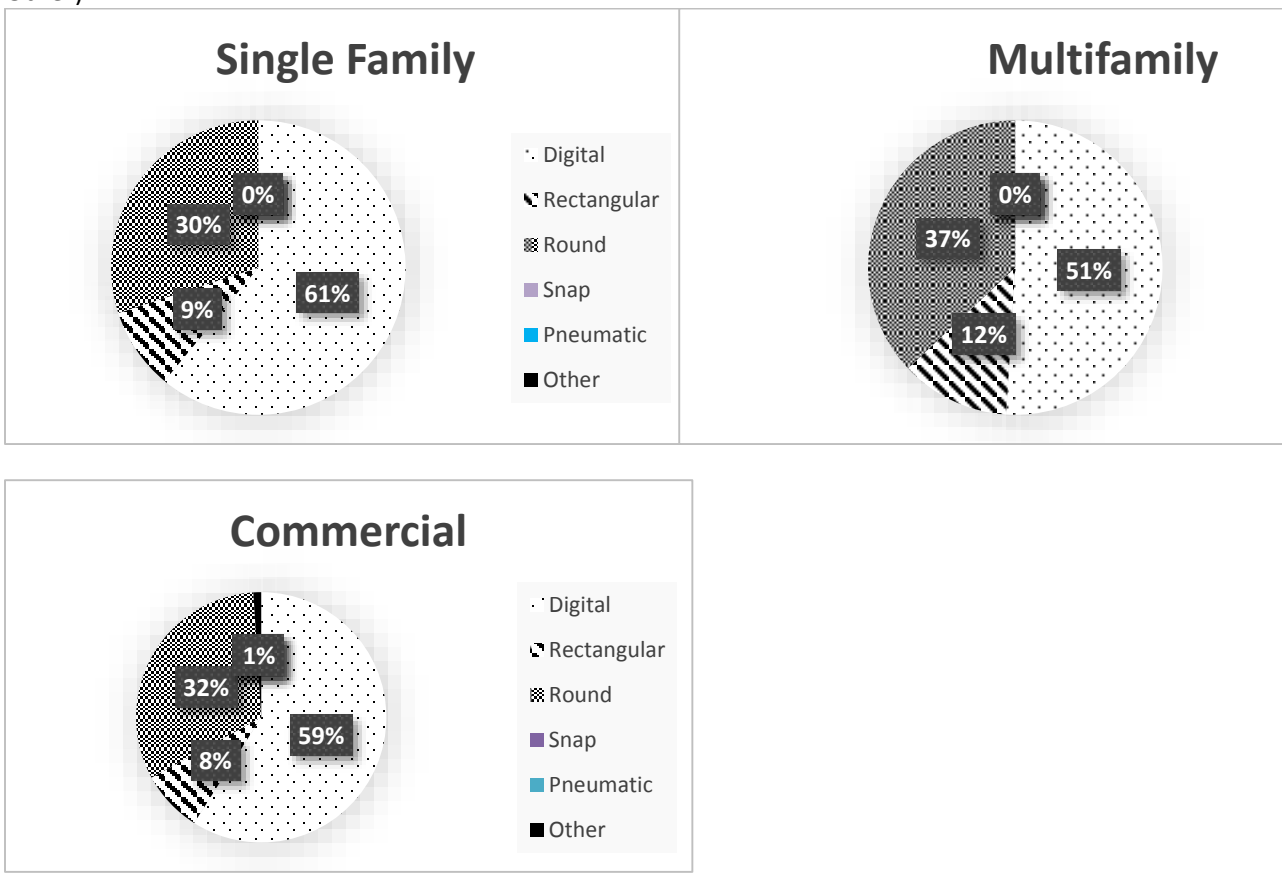
Figure 2.12: Distribution of Thermostat Types in Residential (single family and multifamily) and Commercial Buildings in Maine (Percent by type – Digital, Rectangular, Round, Snap, Pneumatic, and Other)



3. Conducting Steps C & D: Estimating the Flow of Mercury-Containing Thermostats from Maine Buildings

This part of the work involved two steps that, together, provide a prediction of the lifetime and annual "flow" of mercury-containing thermostats out of Maine buildings.

Step C – Estimating the "thermostat lifetime" function

This analysis, based on the methods used to predict measure lifetimes and removals of all kinds of energy using equipment, estimates "hazard" functions that relate to the decay and removal of equipment (which may arise from either ceasing to function or removal due to remodeling / replacement). The statistical technique uses information from the lifetimes of measures that have already been removed, *and* the length of time currently in-place thermostats have functioned without removal, to predict how long the remaining equipment will last. The estimation provides an EUL (effective useful lifetime, the median life, or the age at which half of the thermostats would still be expected to be functioning and half failed). The estimation work also provides the annual percent of failures, or an annual flow of removals in percentage terms. In simplistic terms, we then multiplied these annual failure / removal rates times the equipment in place (estimated above) to get the actual number expected to be removed each year from the residential vs. the commercial sectors.[36]

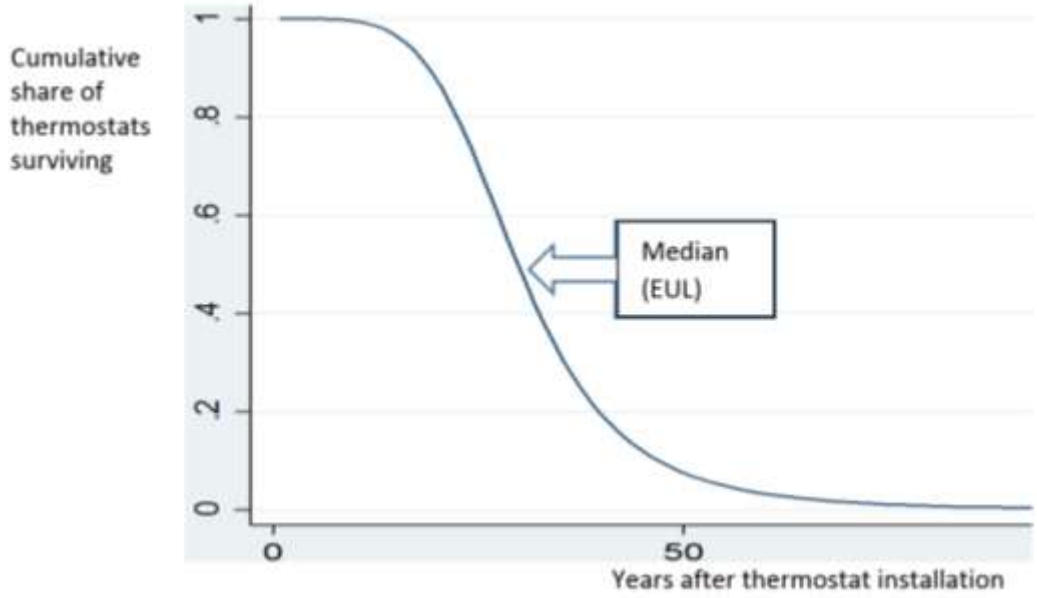
Using data from the survey on years thermostats were installed and removed (or just installed), we tested different statistical models, comparing the performance of different decay functions (specifically log normal, log logistic, Weibull, exponential, and gamma, distributions) to identify the best "fit".[37] The resulting distribution, showing the percent of cumulative failures over the years, is provided in Figure 3.1. The figure implies that the median life of thermostats is about 29 years; that is, half the thermostats installed are would be expected to still be in place and functioning 29 years *after installation*, and the other half would have been removed. Note that digitals (which never contain mercury) were excluded from this estimation work. The estimated 29 median life is substantially similar to the 27.5 year median life results obtained in the California and Illinois studies.[38] This figure is also well within the range of values identified in the literature on thermostat lifespans, which ranges from 20-40 years, with many sources centering around 35 years (see Appendix F). We use these results (the Maine decay or lifetime function) to compute estimated outflows of thermostats in the State.

[36] Step "D" clarifies the refinement needed to this last statement to obtain the final annual estimate.

[37] Performance statistics (log-likelihood) were similar in magnitude; the log-logistic function selected resulted in the most conservative outflows.

[38] Skumatz, Lisa A., "Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings ", Prepared for Thermostat Recycling Corporation by Skumatz Economic Research Associates (SERA), December 2009; Skumatz, Lisa A., Ph.D., "Estimated Annual Outflow of Mercury-Containing Thermostats in the State of Illinois", Prepared for NRDC, Washington DC, prepared by Skumatz Economic Research Associates, Superior, CO, January 2014.

Figure 3.1: Percent of Thermostats Surviving by Age of Thermostat; Function fitted for Maine



(vertical axis is share of thermostats surviving, horizontal axis provides number of years after thermostat installation)

Step "D" - Refinements / Implications and Final Estimations

One last step was required. The hazard function above shows how many of, say, one hundred thermostats, installed at the same time, will still be in place (or not removed) after 1, 10, 20, or 40 years of operation. However, our case is somewhat different. In our estimated statewide inventory, we have many cohorts of many types of thermostats, installed (or "starting") in many different years (see Figure 3.2).

Figure 3.2: Distribution of Age of Mercury Thermostats on the Wall, by Age Groups

Ages of Mercury Thermostats	Percent of Mercury Thermostats on walls in the age group
1-9 years	0%
10-14 years	13%
15-19 years	13%
20-24 years	15%
25-29 years	16%
30-34 years	13%
35-39 years	10%
40-44 years	10%
45-49 years	5%
50-54 years	3%
55 and older	3%
Total (rounding)	100.0%

The computation of annual flows of mercury-containing thermostats from Maine homes and businesses, given the fact that all the thermostats in the marketplace were not installed at one time, is somewhat complicated. To develop the estimate, we used the cumulative distribution and expected lifetime model, along with survey data on the distribution of ages of installed thermostats. First, we classified thermostats into "mercury-containing" and "non-mercury-containing" (the round and rectangular types). Second, we classified all thermostats with ages less than ten years as non-mercury, since mercury models were banned in January of 2006. Then we used the survey responses on the number of mercury-containing thermostats by years of age.

The estimated lifetime function (Figure 3.1) provides data on the percent of thermostats of each age that will "die" / (be removed) that year. A large matrix was prepared that assigned each age of thermostat with the percent that would expire that year; then in the next year, each thermostat gets assigned the percent figure for "death" that is associated with a one-year-older thermostat. Carrying this out across the entire age cohort provided the number of (mercury) thermostats that would flow off walls in each year, from 2015 through 2070.[39]

The figures on the age distribution of mercury-containing thermostats is displayed in Figure 3.2. The figure shows that 13% of the mercury thermostats are 10-14 years old, and another 28% are 15-24 years old. Another 49% of mercury thermostats currently on walls are 25-44 years old. Note, this is distinct from the median age expected for lifetimes for thermostats, which is estimated via the hazard, or lifetime function, as the 29 years referred to in Figure 3.1. One is the median age of thermostats currently on the wall; the other is the estimate of the age at which half the thermostats are expected to be removed from walls, based on the lifetime decay functions estimated for the project.

The computed outflows, in 10 year average increments (Figure 3.3) generally decrease over time. The non-linearity of the result has two main underlying causes. First, the estimated lifetime curve is not linear. The convex and concave portions of the curve imply the incremental outflows will not be constant over time. Second, the age of thermostats in the field is not even across the years.

Figure 3.3: 10-Year Flows of Maine Mercury-Containing Thermostats

Years	Mercury-Thermostats – Average Flow / Year for State of Maine	Mercury Thermostats: Cumulative Percent Flowed Out
2015-2024	16,000	25%
2025-2034	14,000	48%
2035-2044	12,000	67%
2045-2054	12,000	86%
2055-2064	8,000	98%
2065 on	2,000	100%
Total	630,000	100%

The Maine law was established to assure safe recovery of a substantial share of the mercury currently embedded in the thermostats that exist on Maine's walls. Figure 3.3 indicates that it will take until about 2035 for one-half of the mercury-containing thermostats still in place to be removed from buildings in the State.

[39] *We excluded digital thermostats because 1) they do not contain mercury, and 2) they are newer and would have skewed the quartiles toward "newer" equipment, and biased the flows downward. Mercury containing thermostats tend to be older equipment and may be expected to flow out at a faster rate than we would estimate if digital models were left in the computations.*

Appendix A: Literature Review (in Function-Based Context)

There are two key elements to the computation of the denominator of a collection rate for mercury thermostats:

- Step 1: Estimating the "number" of thermostats removed annually (ideally, allowing for change over time as building stock and equipment ages); and
- Step 2: Estimating the percentage of those thermostats removed each year that contain mercury (allowing for change over time to reflect variations based on the age and technology of thermostats installed).

In this appendix, we review the options for these steps, and examples of the literature that attempted to use each option, specifically focusing on four studies:

- King County, "Summary Report: Mercury Thermostats in Commercial Buildings in King County" 11/1/2005, Gail Savina.
- *Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings, Skumatz Economic Research Associates, for Thermostat Recycling Corporation, 2009.*
- "*Measuring Performance of Mercury Thermostat Collection Programs: Approaches and Analysis* ", the Product Stewardship Institute (PSI), 2010.
- *North American HVAC Thermostat Markets*, by Frost & Sullivan, 2003.

This review is similar to a chapter of the PSI study; the chapter was authored by SERA and is adapted here.

Step 1: Determine the number of thermostats coming off the wall.

The following four methods have been used to estimate the number of thermostats coming off the wall:
(1) on-site inspection of buildings and thermostats on the premises (e.g., King County, WA);
(2) occupant reporting of buildings and thermostat ages (e.g., SERA/TRC report);
(3) replacement sales data (using Frost and Sullivan industry data); and
(4) interviews with contractors (PSI report).

The strengths and weaknesses of using each of these three options are summarized in Table A.1 below. Of the three approaches, on-site inspection of a sample of buildings is considered to be the most reliable because it includes direct observation of number, type, and potentially age / failure / replacement by knowledgeable professionals; however it is also the most expensive and time-consuming.[40] By contrast, relying on sales data is less expensive, although the data are not collected specifically to determine the number of thermostats coming off the walls (or coming off the walls in one particular state) and, therefore, require additional assumptions to obtain an estimate. The occupant survey approach can provide a statistically quantifiable level of confidence in the data at a reasonable cost but introduces uncertainty regarding the accuracy of occupant-reported data.

[40] *The statistical reliability of this approach depends on the sample design, sample size, and the degree to which sites that allow the inspection are representative of the overall population of sites.*

Figure A.1: Options for Estimating the Number of Thermostats Coming Off the Wall (Step 1): Strengths and Weaknesses

Option	Strengths	Weaknesses
On-site inspection & analysis	• Reliably observed data • Can collect data for both steps 1 and 2 at the same time. • Provides robust data for projecting changes in thermostat removal over time • Can identify share that is residential vs. commercial if needed	• Relatively expensive and labor intensive to obtain sample large and diverse enough for robust statistical reliability • Must identify suitable "population list,"[41] to sample from; design sample, and check / control for potential non-response bias • Analysis is somewhat complex
Occupant survey responses & analysis	• Data collected based on on-site inspection of equipment; reasonable, but not infallible data • Can collect data for both steps 1 and 2 at the same time. • Provides robust data for projecting changes in thermostat removal over time • Can identify residential vs. commercial sources if needed • Fast to collect/get responses	• Less expensive than on-site data collection, but still requires significant resources • Must identify suitable "population list," design sample, and check / control for potential non-response bias • Analysis is somewhat complex
Sales data	• Easy analysis • Relies on industry supplied data and expert judgments	• Extrapolating national sales/shipment data to a statewide basis does not account for state-specific conditions (e.g., age of building stock, climate, etc.) • Requires purchase of industry report on periodic basis, which requires funding. • Does not provide data for projections over time • Data sources are incomplete (not all firms "report") • No data to support step 2
Contractor Surveys	• Use of "expert" knowledge • Relatively easy to obtain "sample" of contractors from purchased data, Better Business Bureau, etc. • Can concurrently collect information to support Step 2 (percent that contain mercury)	• Very weak response rates, even when partnering with industry associations; poor sample size • Busy, hard to contact, "varied" knowledge and experience; some opinions don't "jibe" with numbers.

a. On-site Inspection and Analysis

In 2005, King County conducted a study of mercury thermostats in commercial buildings, and inspected 1% of the commercial buildings in King County, equal to about 346 structures. King County found that the distribution of mercury thermostats was strongly correlated with building age, and that buildings that were built in the period 1953-1980 were the most likely to contain mercury thermostats. The study found that, on average, 18% of all thermostats inspected contained mercury. Since this study was

[41] *The issue of "population list" is important, and carries over to all surveys described in this document. A sample is drawn from a population list, and if the survey is performed in a way that meets various statistical criteria, the sample will adequately describe the specific population from which it was drawn. That means that any limitations or disconnects in the link between the population list obtained and what one is actually trying to describe must be considered.*

limited to commercial buildings, it cannot be used to estimate the number of thermostats in residential settings. Also, the study focused on measuring the existing stock of mercury thermostats and did not address how quickly those thermostats were coming out of service. The study provided the basis for developing a mathematical model of the relationship between building characteristics (age, size, heat source, predominant use) and the presence of mercury thermostats. This model could potentially be adapted by other states to estimate the number of mercury thermostats available for collection in commercial buildings in their own states. The data collected in King County, however, may not be representative of other states due to a variety of factors. As noted previously, replacement rates and the fraction of thermostats that contain mercury are likely to be lower in King County than in eastern states.

Although on-site inspections are time and resource-intensive, if resources are available - *and a high level of confidence is needed* - it would be possible to draw a sample of buildings in the state or local area and inspect them for the information needed. Based on the information collected from a combination of site visits and occupant interviews (which are needed for age, change-outs, etc.), a model addressing thermostat usage, building parameters, and building stock would then have to be developed by each state or locality to estimate the number of thermostats coming off the wall each year (as is also required in the SERA/TRC approach, below).

b. Occupant Survey Responses and Analysis

California's mercury thermostat law requires that thermostat manufacturers estimate the number of mercury thermostats available for collection, and provide results to the CA Department of Toxic Substances Control (DTSC). In the fall of 2009, Skumatz Economic Research Associates (SERA) conducted a pilot study on behalf of TRC to demonstrate an approach for possibly determining that number. SERA used an online occupant survey to determine the number, age, and type of thermostats in place (and potentially available for removal) in both residential and commercial buildings, as well as those removed.[42] The survey results were validated with 30 on-site visits conducted in the San Francisco Bay Area. (These validation visits can be used to collect data for both Step 1 and Step 2.) Based on data from the more than 800 survey responses received, SERA developed a statistical model of expected thermostat removal patterns for buildings of different ages and types. This model was then used to assess annual and projected thermostat removals. The Skumatz Economic Research Associates (SERA), entitled "*Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings"*, estimated that 19.8 million thermostats are in place in California businesses and residences. The weighted average age of thermostats in place is about 12.5 years. The survey determined that between 22% and 46% of thermostats currently in place in commercial buildings in California contained mercury, and between 27% and 47% of residential thermostats in place contained mercury. The percent of thermostats in place that were digital was 54% in CA businesses, and 53% in CA residences.[43]

c. Sales data

For those unable to undertake one of the other two location-specific approaches owing to resource constraints, an alternative approach is to make computations using data collected on the number of

[42] A "validation" survey (30 on-site visits in the San Francisco Bay Area) was also conducted to provide feedback on the accuracy of collecting data in this manner. Validation visits of this type can be used to collect data for both Step 1 and Step 2.
[43] Given that digital thermostats are 100% non-mercury, the "high end" of the ranges reported in the previous sentence are computed assuming all of the non-digital models are mercury.

thermostats sold for replacement, and assume that all thermostats being replaced will be either disposed of or recycled. The steps and necessary assumptions are detailed below.

Nationwide thermostat replacement sales numbers are provided in a 2003 report,[44] *North American HVAC Thermostat Markets*, by Frost & Sullivan[45]. The study provides detailed information on the number of thermostat units sold in North America for residential and commercial markets. The report provides a breakdown (by sales revenue) of the percentage of units sold for new construction and replacement markets. The difficulty of applying this report is that it provides an estimate of the replacement market, but not the share of the equipment being taken out contains mercury (see options for Step 2 below).

Applying the replacement percentages to the unit sales data produces an estimate of replacement sales for thermostats for North America. The U.S. market comprises 90% of the North American market. In a 2010 report entitled "*Measuring Performance of Mercury Thermostat Collection Programs: Approaches and Analysis* ", the Product Stewardship Institute (PSI) scaled these national estimates to the Commonwealth of Massachusetts.

d. Contractor Surveys as a Source

The PSI study "*Measuring Performance of Mercury Thermostat Collection Programs: Approaches and Analysis* " (2010), also tested the feasibility of gathering data on thermostat replacements and mercury content based on surveys with contractors. They partnered with two industry associations in an attempt to achieve high response rates, but in a nationwide survey, received no surveys from a number of states, and no more than 10 from any except one state. More information about this study is provided below under Step 2.

Step 2 –Estimating the Percentage of Thermostats that Contain Mercury

Three main methods have also been used for assessing Step 2:

- On-site expert inspection of the share of installed thermostats (in general or by "type") that contain mercury (e.g., SERA/NEMA and King County).
  Occupant survey / reports (e.g., Skumatz / NEMA[46] report), and
- Contractor surveys.

The strengths and weaknesses of these approaches for "Step 2" are summarized in Figure A.2 below.

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[44] These reports are updated periodically and must be purchased from Frost & Sullivan. The 2003 report was the latest report available to government agencies.

[45] Frost & Sullivan publishes a periodic market description of the North American thermostat market. The data and estimates in the report are derived from surveys and interviews from the market participants, which are cross-verified where possible by interviewing other market participants in the industry, as well as end users and customers. The primary data are also evaluated against secondary data sources available publicly and in the company's databases. Market forecasts are derived using an expert opinion consensus model. Given the cost (approximately $5,000) and the emphasis on market descriptions and challenges, the document is primarily used by industry participants. For more information on the 2006 Frost & Sullivan report, see http://www.frost.com/prod/servlet/report-brochure.pag?id=N063-01-00-00-00.

[46] This study also used some on-site validation to examine the share of each thermostat "type" remaining in place (for future removal) contained mercury; however, these inspected whether the remaining thermostats

Figure A.2: Options for Estimating the Percentage of Thermostats Replaced that Contain Mercury

Option	Strengths	Weaknesses
On-site inspection	• If conducting Step 2 using this method, data for Step 1 can be collected at the same time. • Same pros and cons as Table 2.	• Same pros and cons as Table 2 • Requires qualified staff able to remove covers and inspect units
Occupant survey	• If conducting Step 2 using this method, data for Step 1 can be collected at the same time. • Same pros and cons as Table 2.	• Same pros and cons as Table 2 • Although mercury content is clear for some thermostat types (e.g. digital), it is difficult for residents to be certain if some types of thermostats contain mercury (e.g. round types, etc.) unless covers are removed.
Contractor survey	• Straightforward estimates of share of mercury-containing thermostats can be computed from data collected on total thermostats removed and number containing mercury.	• Must identify suitable "population" list, design sample, and check / control for non-response bias • Generally does not provide data to help estimate how the share of thermostats that contain mercury changes over time[47] .

a. On-Site Inspection and Occupant Survey

If either the on-site inspection or the occupant survey approach is used for Step 1, data can also be obtained for Step 2 at the same time to determine whether or not a thermostat contains mercury. If on-site inspection is used, high quality data will likely be obtained because inspectors are skilled at identifying thermostats that contain mercury. However, as mentioned above, this approach is resource intensive. If the occupant survey approach is used, the data will be less reliable since it relies on occupants, not professional contractors, to identify whether the thermostat contains mercury.[48] However, this approach is less resource intensive than on-site inspection. Results from both are subject to the issue of non-response bias, if patterns of homes or businesses deny access to the building or refuse to return the survey.

b. Contractor Surveys

Regardless of the approach used in Step 1, a heating and cooling contractor survey can provide data on the number of thermostats removed by the contractors from walls over a specific period of time and how many contain mercury. If either the on-site inspection or occupant approach is used, the contractor survey can still be used to corroborate data about the percentage of thermostats that contain mercury. If either of those two approaches is *not* used, a well-designed and executed contractor survey could theoretically provide the necessary information to calculate a thermostat collection rate. Two low-cost pilot tests were conducted, and summarized in PSI study "*Measuring Performance of Mercury Thermostat Collection Programs: Approaches and Analysis*", (2010).[49]

[47] One can gather data to address this issue or surveys can be performed periodically to update the data (for goal-setting into the future).

[48] Some have suggested that occupants be asked to open the thermostat to determine if it has a mercury ampoule. However, this approach is not recommended for safety reasons.

[49] The author of this Rhode Island study (Skumatz) also served as an advisor on this PSI research.

In the spring of 2010, PSI enlisted the help of two associations of heating and cooling contractors – the Air Conditioning Contractors of America (ACCA) and the Plumbing, Heating, and Cooling Contractors (PHCC) – to gather information on the percentage of thermostats removed that contain mercury. PSI implemented two surveys: (1) a national survey of ACCA and PHCC members and (2) a statewide survey of contractors in Massachusetts. They tried on-line surveys to a membership list of 3000 contractors, and received 160 responses (15 states had no responses, 10 or more responses were received from 6 states). The responses were non-random, and compromised the analysis, but the pilot was useful in pointing out that gathering data from contractors was not, as hoped, quick, cheap, and reliable. The research was useful, and the report works to identify some possible strategies to improve the approach; however, strategies to achieve results inexpensively were not uncovered.

A second pilot, conducted totally in Massachusetts, involved interviews with 65 (of the 81) ACCA member companies. They were provided a tracking form to provide data on the percent of thermostats they removed / received contained mercury. Each firm was called at least 3 times over a two-month period, to remind them about tracking. An analysis of the 27 firms responding, which was too small (and not complete / random enough) to provide meaningful analysis. Again, suggestions were made to improve the approach (more follow-up calls, etc.); however, the search for a low-cost, easy approach using contractors was shown to be less easy than expected / hoped.[50]

[50] *The author of this study for Rhode Island / NRDC was an advisor/ reviewer to the PSI study.*

Appendix B: Response Rate Comparisons

Figures B.1, B.2, and B.3 compare the response rates for residential households (single vs. multi-family) and commercial businesses, by county, to the census shares of "population" for each group. The results show that we received responses from all across the state, in rough proportion to the census shares. Although there are differences, there did not seem to be significant enough in the way of systematic differences to warrant complex re-weighting by county.

Figure B.1: Graph of Single Family Response Rates by County Compared to Census

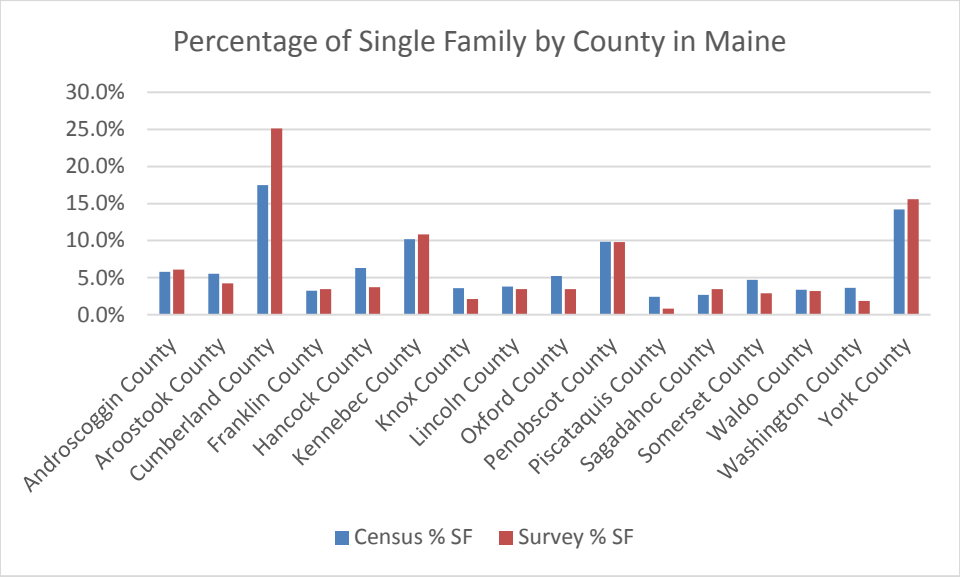


Figure B.2: Graph of Multifamily Response Rates by County Compared to Census

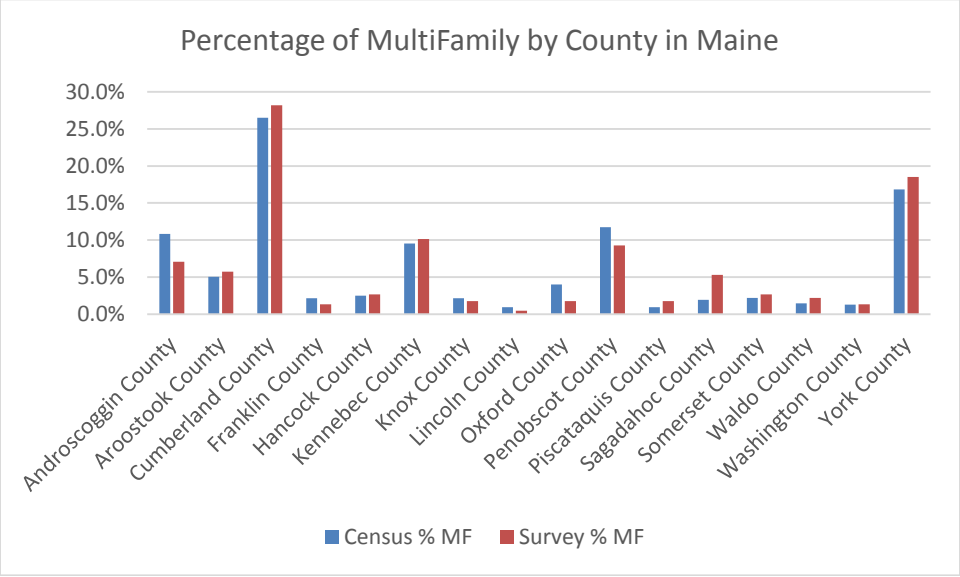
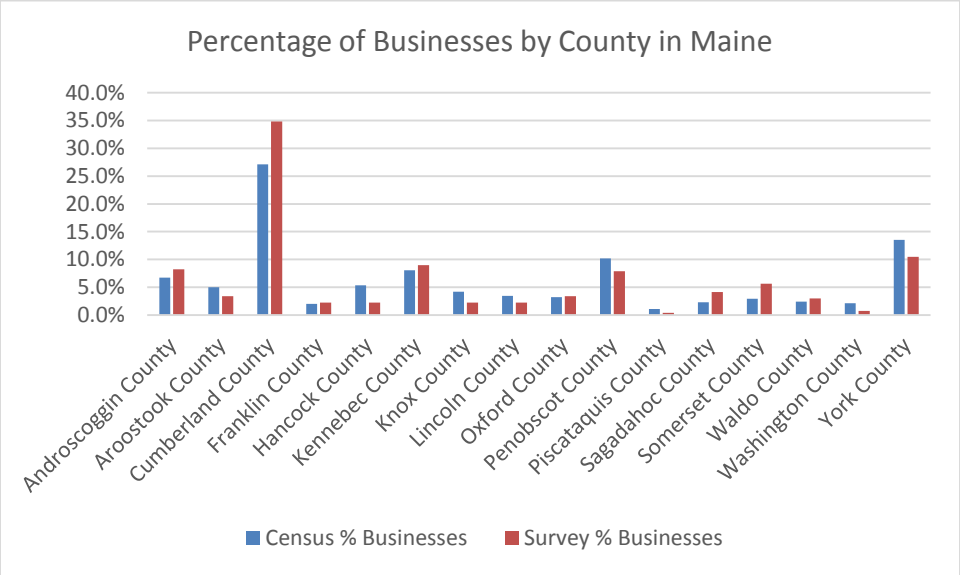


Figure B.3: Graph of Commercial Response Rates by County Compared to Census



Appendix C: Detailed Validation Results

Figure C.1: Number and Percent of Mercury-Containing Thermostats from On-Site Inspections in Maine

TYPE- ME	Number reporting	Sector	# Therms **Total** from Survey	**Total** Therms verified
ME Camera	36	SF	101	102
ME Camera	29	MF	47	50
ME Camera	31	BUS	167	129
Total Camera	96		315	281
ME Onsite	19	SF	54	51
ME Onsite	5	MF	39	36
ME Onsite	22	BUS	145	160
Total Onsite	46		238	247
Total Camera & Onsite	142		553	528

Figure C.2: Validation Results on Count of Thermostats, Total and by Major Thermostat Type in Rhode Island

	Mercury Containing	Non-Mercury	Total
Total number of mercury-containing thermostats reported from validation sample's on-line survey & interviews	238	315	553
Number of mercury-containing thermostats from camera and on-site validation, same sample	262	266	528
Resulting potential "adjustment" factor for totals	110%	84%	95%

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Appendix D: Thermostat Expert Interviews

Mercury Thermostat Overview

To establish baseline information for mercury containing thermostats, we interviewed a variety of industry experts. We specifically contacted those in the industry from The States of New York and Maine and included others from across the country in California, Georgia, Indiana, Colorado and South Dakota. Information was gathered from control manufacturers Honeywell and Johnson Controls, equipment wholesalers, recycling center collectors, and representatives from multiple industry associations. HVAC engineers and contractors were able to provide the most detailed insight into common practices for the various sectors (MF, SF & Commercial). Overall, we contacted 74 different individuals, companies, and associations and were able to gather in depth information from 18 of those contacts. The questions and responses of the interviews are below.

Questions asked:

- What types and shapes of thermostats most likely contain Mercury?
- When were most mercury containing thermostats installed and replaced?
- How long should thermostats last?
- Can you tell by looking at them if they contain Mercury?
- How many thermostats do you typically find in a SF home?
- How many thermostats are in common areas of MF or Commercial Buildings?
- Some people say they don't have any thermostats in offices. Do some buildings only have them in maintenance areas?
- When and where are pneumatic thermostats used? Would they be in an office or only in maintenance areas?

Overview responses to questions:

1) **What types/shapes of thermostats most likely contain Mercury?**
   -Digital screen with LCD font- about 98% of time they do NOT contain mercury
   -All round thermostats before mid 1990's contain mercury (as well as many of the rectangular Honeywell thermostats)
   -Rectangular Honeywell with two levers, 80% of time contains mercury
   -Honeywell T87 most common mercury thermostat model
   -White Rogers also sold mercury thermostats
   -If you could adjust the temperature by turning a dial or moving a lever up and down, then it most likely had mercury.
   -Most all of the ones over 30 years old.

   OVERALL RULE OF THUMB: DIGITAL means NO MERCURY, NOT DIGITAL means Likely MERCURY (especially round Honeywell models)

2) **When were most mercury containing thermostats installed? When were they replaced by non-mercury thermostats?**
   - Installed starting in 1950's

- Replacements started in 80's when programmable came out and widely used
- 90's digital became popular (for res. and commercial)
- Had one from 70's, still worked, changed unit so had to upgrade to digital. New units usually require digital.
- Rarely are there mercury containing thermostats in commercial.
- ***Most common response: Installed before the 90's***

3) How long should they last?
- Last still mercury bulb breaks or has an issue.
- Last 20+ years
- Mercury thermostats don't get removed unless an entire HVAC system is being replaced.
- They could last forever, very simple, nothing can really go wrong with them. They may lose calibration, but will still work.

4) Can you tell by looking at them if they contain Mercury?
- No, have to open up the back and look for bulb
- Rule of thumb: again digital=no mercury, non-digital=mercury.
- Spring on board on the bottom with a movable tab=most likely not mercury
- Round Honeywell=most likely mercury (BUT Honeywell just came out with a "Retro" round model that is new and does not contain mercury but looks like the old T87 models that do have mercury.)
- No, but it is easy to open and see the mercury tube.
- No but most apartments have upgraded to digital, more efficient even if they haven't upgraded their system, but most have upgraded their systems.
- 11 years he's owned this business. They have been tracking for 8 years, less than 20 have had mercury. Some small retail (like strip malls may still have them since many still have very old (30+) rooftop units, but none of the multistory buildings.
- In 28 years of working, have not seen one in commercial or MF. In the last 20 years all have been replaced.

5) How many thermostats do you typically find in a SF home?
- Typically 1, unless base board heating then more thermostats depending on zoning in the home.
- Usually one per system unit. Some of the newer digital ones may have zones

6) How many thermostats are in common areas, MF or Commercial?
- Usually 1 common area with thermostat
- In multiple units then possibly 4 thermostats
- Thermostat may be placed in boiler room, supers office, or basement area
- Also some MF may have a thermostat in each unit
- Usually 1 per hallway, 2 in fitness area, one in the leasing office, 1 or more in a large atrium area and then also one for the glazing to adjust for sunlight heating up areas and then one in each unit.

7) Some people say they don't have any thermostats in office. Do some buildings only have them in maintenance areas?
- Yes, mostly in maintenance area so no one will touch the thermostat. New buildings are computerized so no thermostat to adjust.

- Most will have a local area to adjust up and down (which will be digital), but there will be an overall one in the maintenance area that is the main control.

8) When and where are pneumatic thermostats used. Would they be in an office or only in maintenance areas?

- Typically large industrial buildings, or large commercial buildings no mercury
- Yes, in maintenance area
- They might have them in office areas, but most have been replaced. There would be the general one in the maintenance area then the ones in the offices that can move up and down. Usually, it runs the fan and the main control one sets the temperature.
- Pneumatic thermostats don't contain mercury, but often the covers have mercury thermometers in them. The covers are usually reused when replacing thermostats unless they are changing the type of thermostat. (from contractor who called for survey)

On pneumatics: need to know if they look different and whether they contain mercury.

- Pneumatic does not typically contain mercury. One contractor said if they are VERY old they may but that is NOT how pneumatic works.
- Yes, they are very industrial looking. They never contain mercury, because they are mechanical
- They never have mercury. The system is outdated and very few buildings use that system, maybe 1% of large commercial will still have them, never small retail.

How do they work?

- Pneumatic works by being hooked up to a heating and/or cooling system. It is set to react to a specific temperature and is connected to numerous tubes. It is able to tell the temperature by how much pressure is contained in the tubes. It is all based on air pressure and the tubes. Mercury is typically never used in these types of systems since it is not needed.
- They system is no longer in demand because of the tubing needing to be run throughout the building.

Are pneumatics the types of controls that are in place in large buildings with big boilers like in NYC? And places with old water pipe radiator systems? Where else are they used?

- What I was told is that they are in large industrial buildings and large commercial buildings typically in the maintenance room (which sometimes is the boiler room).
- They never use pneumatic thermostats, too many moving parts and tubes
- Maybe 75% of old buildings used to have pneumatic. They never had mercury. They still sell maybe 40% pneumatic thermostats.
- Every once in a while they see old pneumatics come out of buildings, but they never install or sell any. It's all digital now.

Summary

IMERC Fact Sheet Mercury Use in Thermostats January 2010. Submitted to the Interstate Mercury Education and Reduction Clearinghouse.

Table 1: Total Mercury Sold in Thermostats (pounds)			
2001	2004	2007	2010
29,253 (14.6 tons)	28,901 (14.5 tons)	7,485 (3.7 tons)	330 (0.17 tons)

Also discusses state legislation and states that are starting collection programs.

Review of the Thermostat Recycling Corporation Activities in the Northeast. By the Northeast Waste Management Officials Association, (NEWMOA) November 2001.
Reviews wholesalers participation in the program
CT- 3%
ME-11%
MA- 6%
NH- 0%
NY-2%
RI_ 2%
VT- 39%
Use estimates through the TRC program on how many potential could be collected and by the 1994 EPA report.

Survey of Thermostat Recycling Corporation (TRC) Wholesalers , June 2003, Prepared by the Northeast Waste Management Officials' Association (NEWMOA).

- The number of HVAC and electrical wholesalers currently participating in TRC's recycling program is substantially less than what the TRC indicates on its Web site. Only half of the 55 participants listed are actually participating wholesalers.
- Of the 43 wholesalers listed as current participants that NEWMOA surveyed with a visit or phone call, approximately one-third were no longer participating.
- Wholesaler collection programs have mixed success. About half of the wholesalers surveyed that were still participating reported that they collected a moderate to large amount of thermostats, while the other half reported that they collected very few. Nearly all of those that collected few thermostats cited lack of interest among contractors as the primary reason why.
- Possible reasons for good collection programs include strong interest on the part of the wholesaler (e.g., Interstate Electric Equipment), lots of promotion for mercury recycling in the community (e.g., the Burlington wholesalers), peer influence (i.e., bins that are frequently full with thermostats may encourage other contractors to bring in theirs), and the type of contractor the wholesaler services
- (i.e., contractors handling a higher volume of thermostats may be more apt to recycle). Conversely, some wholesalers in communities with strong recycling programs may collect fewer thermostats if contractors have other places to take them, such as the local DPW.
- Corporate wholesaler offices are not providing sufficient information or support on the recycling program to their branch stores. As a result, participation by branch offices is spotty and sometimes weak. Some branch stores knew very little about the program. Other branches defer

decision making on the program to the corporate offices, but the corporate offices do not appear to actively promote the program.

- Many wholesalers do not understand well how the program works.

Appendix E: Survey Instrument

Maine Recycling/Hard-to-recycle Survey

Introduction
The State of Maine working to improve options for hard to recycling items such as wall thermostats that sometimes contain mercury. If improperly disposed, they can have negative effects on waterways, fish, and humans. We are researching the number and types thermostats that are in existing buildings in the State. The results of this study will be used to improve the design of recycling and disposal programs across Maine.

Your building/home is one of a small sample selected to "stand in" for all the buildings / homes in the State of Maine, so your help on this survey is VERY important. It should take approximately 5 MINUTES to complete this survey. You will then have the option to enter into a drawing for one of SIX $100 GIFT CERTIFICATES to Best Buy or Target. Your individual answers will be kept CONFIDENTIAL and will not be used to identify you or your building in any way. You may also sign up to REQUEST A COPY of the results of the survey.

We really need and appreciate your help! Please help keep mercury out of our environment!

***1. For which type of location you will be answering? (* Required Answer)**
- I am answering as a HOUSEHOLD (house/ apartment/ condo/ home office).
- I am answering for my BUSINESS / OFFICE (employee / manager / owner).
- I am answering for MULTIPLE BUSINESSES or TENANTS- Whole Building information (Property Management or Owner/ Building Engineer).
- I am answering from a MIXED residential and commercial building.

***2. Mixed Residential / Commercial Type ONLY. I am responding as a... (Please check best answer)**
- Combined commercial / residential building (I am responding as a BUSINESS)
- Combined commercial / residential building (I am a RESIDENT and am responding as a RESIDENT)
- Combined commercial / residential building (I am responding for the WHOLE BUILDING- Multiple tenants or businesses)

Business- Employee, Management, Business Facilities WALL Thermostats
Responses to the following set of questions will help the State improve possible mercury containing thermostat recycling programs and keep mercury out of the environment. This question is important. Please take a moment to look around your business to see if you have wall thermostats.
APPROXIMATELY how many wall thermostats are located in your business?
***1. Number of thermostats ON THE WALL (not on baseboards, radiators, window / wall units, or remotes)-**
- Number of Thermostats ON the WALL?
- Number still working?

If more than 50, please list number

2. If answered ZERO or Don't know--WERE there WALL thermostats that have been removed?

- Currently NO thermostats, never were thermostats
- Currently NO thermostats, but there used to be
- Have thermostats-provided number above
- Currently NO thermostats, Don't know about before

Thermostat Pictures BUSINESS Employee/ Owner/ Manager
These are general thermostat "types" for the following questions. Please look around your business to determine the approximate type and number in your business. Brand does not matter.

***1. This question is important: a full row must be completed for prize eligibility. Please list the approximate NUMBER and TYPE (from above) of wall thermostat in your BUSINESS.**
Number currently in your business ==> Number still working ==> Estimated year they were installed

- DIGITAL Type (any shape)
- RECTANGULAR / Square (not digital)
- ROUND (not digital)
- SNAP (not digital)
- Pneumatic (not digital, not common)
- Other Non Digital WALL Thermostat
- Control ON window/wall unit, baseboard, radiator or remote
- Other (please specify larger numbers, clarify other items)

***2. Approximately how many total WALL thermostats were replaced / removed? (Drop down menu)**
Specify larger numbers / Other (please specify)

Whole Building- (Owner, Property Management, Facilities) WALL Thermostats
We are interested in learning more about hard to recycle items such as WALL thermostats in Maine, especially those that may contain mercury. This question is very important. Please take a moment to walk around or think about thermostats you may have on the walls.
1. This building has multiple tenants or businesses (if not go back and choose residential or business) and is a....

- residential building
- commercial building
- mixed commercial and residential building

***2. Number of thermostats ON THE WALL (not on baseboards, radiators, window / wall units, or remotes)- APPROXIMATELY how many wall thermostats are located in this BUILDING?**

- Number of Thermostats ON the WALL?
- Number still working?

- If more than 50, please list number

3. If you answered ZERO or Don't know-WERE there WALL thermostats that have been removed?

- Currently NO thermostats, never were thermostats
- Currently NO thermostats, but there used to be
- Did not say zero- provided number above
- Currently NO thermostats, Don't know about before

Thermostat Pictures WHOLE- Building Owner/ Management Company/ Facilities Personnel

We are showing a few pictures of general "classes" of thermostat types below. Please answer for types closest to the ones in your building. Brand does not matter. WALL Thermostat Types for following questions.

***1. This question is important: one entire row MUST be answered for prize eligibility. List the approximate NUMBER and TYPE (from above) of thermostats in this BUILDING.**

Currently in WHOLE building? / #Per apartment, condo or, Zone?/ #still working?/Year installed
<"Thermostat type" list from Question above>

***2. Please give best estimate for the number of condo / apartments or Zones for this building.**

Please list number if over 300

3. Are there wall thermostats for central heating in the common areas such as.... (Please put in number where it applies)

- # In the reception / entry way
- # In the hallways
- # In the atrium
- # In community room / workout space
- # In other areas

***4. Approximately how many total WALL thermostats were replaced / removed? (Drop down menu)**

Specify larger numbers / Other (please specify)

Thermostat Removal Commercial

1. Using the above thermostat types, can you report how many of each type have been removed?

(Best estimate, brand does NOT matter.)Number that used to be in building but have been removed ==>
Year they were removed (best estimate) ==> Approximate year they were originally installed
<Thermostat type" list from question above.>

2. To the best of your knowledge, why were the wall thermostats removed and/or replaced?

3. Do you know what happened to the removed wall thermostats?

4. About how many removed or unused WALL thermostats do you have awaiting discarding or recycling? (Drop down menu)
Other (please specify)

Building Info- General
1. Approximately when was this building built? (best estimate).
If other, please describe age of building as close as you can..

***2. How many years have you worked at this location? (Please mark the closest number)**

3. Was the heating / cooling SYSTEM replaced or updated without removing existing wall thermostats?

***4. Please click according to how you have been responding to move you to the final questions.**

- Business Employee / Manager / Owner / Facilities - for ONE business only
- Property Management- for WHOLE building-Multiple tenants
- WHOLE building- Multiple tenants or businesses Engineer/ Facilities
- Building Owner- for WHOLE building- Multiple tenants
- Other (please specify)

Business Building info
1. Does your business / building have central heating or cooling? (Check all that apply)

- EMS (Energy Management System) / BMS System
- Heating and/ or Cooling controlled centrally (not controlled by our business)
- Central HEATING/COOLING controlled with a WALL thermostat in our business
- Central COOLING ONLY with a WALL thermostat (not window wall units)
- Central HEATING ONLY with a WALL thermostat
- Baseboards only (control on WALL)
- Baseboard heating only (control on baseboard)
- Radiator only (control on WALL)
- Radiator heating only (control on radiator)
- Wall / Window units only
- No, we have neither
- Not sure
- If other, please specify

***2. About how much of the building's space does your business occupy? (Make your best guess) Put 100% if yours is the only firm in the building**.

- <10%
- 10-19%
- 20-29%
- 30-39%
- 40-49%
- 50-59%
- 60-69%
- 70-79%
- 80-89
- 90-99%
- 100% (only firm)
- Don't know

Other (please specify)

3. What is your best estimate of the size (square footage) of YOUR BUSINESS? (Drop down menu)

***4. What is your best estimate for the number of employees in this BUSINESS? (Drop down menu)**

Whole Building Information- Building Owner / Management / Facilities Personnel

1. What is your best estimate of the size of this Whole Building?

- Whole Building Square Footage
- OR Square Feet per floor & number of floors
- OR Square Feet per unit & number of units
- Please specify number of floors

2. What is your best estimate for the number of employees (or residents) in this BUILDING? (Drop down menus)

Number currently in WHOLE building Number of Employees Number of Residents

3. What type of heating/ cooling system is in this building?

- EMS - Energy Management System
- Radiator heating only (Control on radiators, not wall)
- Radiator heating only (Wall Controls/ thermostats)
- Baseboard heating only (Control on baseboard, not wall)
- Baseboard heating only, (wall controls/ thermostats)
- Other / Don't know - Other (please specify)
- Central HEATING ONLY (Including boilers and other whole building types, controls not on units)
- Combined central HEATING / COOLING (Including boilers and other whole building types)
- HEATING and / or COOLING Controlled Centrally (residents/ employees can't adjust)

Residential Hard to Recycle and Thermostats

In order to keep mercury out of the environment The State of Maine is very interested in learning about hard to recycle items, and the disposal and replacement of WALL THERMOSTATS that may contain mercury. Please think about thermostats that you may have on the wall in your home.
This question is very important; (we appreciate a quick walk-around wall count)

***1. Number of thermostats ON THE WALL (not on baseboards, radiators, window/wall units, or remotes)- Approximately how many wall thermostats are located in your household?**

- Number of Thermostats ON the WALL?
- Number still working
- If more than 30, please list number

2. If you said ZERO-

- Did there used to be WALL thermostats that have been removed?
- Currently NO thermostats, never were thermostats
- Currently NO thermostats, but there used to be
- Did not say zero- provided number above
- Currently NO Thermostats- Don't know about before

Residential - Thermostat Pictures

We will be asking questions about the following WALL thermostat "types".

Please answer for ones that look closest to the ones in your home. Brand does not matter.

WALL Thermostat Types

***1. Which of the above pictures best match the WALL thermostat(s) CURRENTLY in your HOUSEHOLD?**

This question is very important: a full row must completed for prize eligibility.

Number currently in home (or unit, if apartment)=> Number still working ==> Estimated year installed

<"Thermostat Type" list from question above>

***2. Approximately how many TOTAL WALL thermostats were replaced / removed? (Drop down menu)**

Clarify larger counts; Other issues (please specify)

Residential - Thermostat Removal 1

1. Using the above thermostat types, can you report how many of each type of WALL thermostats have been removed? (Best estimate, brand does NOT matter.)

Number that used to be in home (or unit) but have been removed ==> Year they were removed (best estimate) ==> Approximate year they were originally installed

<"Thermostat Type" list from question above>

2. To the best of your knowledge, WHY were the wall thermostats removed and / or replaced? (Check all that apply)

Residential- Thermostat Removal 2

1. WHO made the decision to remove / replace the wall thermostats and / or heating system?

2. About how many removed or unused WALL thermostats do you have awaiting discarding or recycling? (Drop down menu)

Other (please specify)

House/ Apartment/ Condo Type

These last few questions are needed to help us analyze the data. They will NOT be used to identify you.

***1. I am responding as a... (Please check the best answer)**

- HOUSEHOLD Single family home, separated from other homes
- HOUSEHOLD Single family home, attached (town home, condominium)
- HOUSEHOLD Apartment / Condo with 2 - 4 units

- HOUSEHOLD Apartment / Condo with 5 - 19 units
- HOUSEHOLD Apartment / Condo with 20 or more units
- HOUSEHOLD Manufactured home / Mobile home / Trailer
- Other, but residential
- Other (please specify)

Multifamily / Apartment

***1. If you are in a multifamily building: Approximately how many apartment units are in this building? (Drop down menu ranges)**

Please list exact number of units if known

2. If you live in an APARTMENT, are there WALL thermostats for CENTRAL heating in the common areas such as.... (please put in number where it applies)?

- # In the reception / entry way
- # In the hallways
- # In the atrium
- # In community room / workout space
- # In other areas

Residential / Household Heating and Size

The following questions are for comparison only. Please give your best estimate.

1. Does your HOME have central heating or cooling? (check all that apply)

- HEATING and / or COOLING controlled centrally.(not by you)
- Central HEATING/ COOLING you control with WALL thermostat
- Central COOLING ONLY with a WALL thermostat (not window/ wall units)
- Central HEATING ONLY with a WALL thermostat
- Baseboard only- WALL control/ thermostat
- Baseboard heating only (control on baseboard)
- Radiator heating (WALL control / thermostat)
- Radiator heating only (control on radiator)
- Wall/ Window units only
- No, we have neither
- Not sure
- If other, please specify

2. Have there been any changes to the heating / cooling system and thermostats?

3. Approximately when was this home / building built? This information is very important – please make your best estimate. (Drop down menu)

Other- please specify

4. About how large, in square feet, is your residence? (Drop down ranges)

(NOT including garage or unheated spaces like crawl spaces) Other (please specify)

***5. How many...**

- Bedrooms are in your residence?
- Bathrooms are in your residence?

Head of household

This information is for statistical purposes only and is kept confidential.

***1. Approximately how many years have you (or the head of household) lived in this home? (Drop down menu)**
(If less than 1 year, put 1) Other- please specify

2. Including yourself, how many persons normally live in this residence on a full-time basis? (Drop down menu)

3. What is the highest grade of schooling completed by the Head of Household?

4. Please provide an age range for the Head of Household.

Method of Contact
***1. Click by which means you were notified.**

- PostCard / email/ phone / voice mail / other options

Resident postcard
***1. Please tell us which color postcard you received.**

Email Code
Please list which Business Code was listed in your email.
***1. Business code listed at top of email or from phone message.**

Postcard commercial / business
1. Please list which color postcard you received.

Prize Drawing
Thanks you very much for taking the time to complete our survey. Both your time and input are appreciated.

***1. What is the 5-digit zip code for this building / home?**
Zip code

***2. Please list the county for this building / home.**

***3. Were you aware that there could be mercury in older, non-digital wall thermostats?**

- Yes
- No
- Not sure

4. What items / materials do you have a hard time disposing? (Open ended)

***5. PRIZE: Would you like to be entered into the prize drawing?**
Yes
No

Prize Contact Information
***1. Please enter your contact information to be eligible for the prize.**

Thanks!
THANK YOU for completing our survey!
If you have any other comments or questions about the survey or project please let us know.
Survey Summary -You can request a summary of the results that will be included in our report for the state by providing an email address below.

Appendix E: Notifications

The wording of postcards are provided in this appendix. The questionnaire is provided in another appendix.

Postcard Screenshots (phone numbers and websites edited out).

Figure E.1: Residential Postcard

Figure E.2: Commercial Postcard

Figure E.3: Text from Typical Email Survey Appeal
TO: New York Business Owner/ Manager/ Employee / Facilities Manager
RE: Improving Recycling for Businesses in New York – Important Information for the State
OPTION: ***Drawing one of six $100 gift cards.***
BUSINESS CODE: SMALL

Hello,
We are contacting a few select businesses around the State and are asking for your help. We are hoping you could take a few minutes to provide information that would **help improve commercial recycling programs** for hard-to-recycle materials *such as mercury thermostats* in the **State of New York.** We know your time is valuable so we've prepared a short survey through the link below. *(Please feel free to answer yourself or forward to someone else at the firm who knows recycling & facilities.)*

https://www.surveymonkey.com/s/xxxxxxxxxxx or at **866-XXX-XXXX**
Your **BUSINESS CODE: SMALL**

As a "Thank You", for completing the survey, you have the option to enter into our **drawing for one of six $100 gift cards.** (Limited time offer – try to respond in the next week or two!)

The results of the survey will be used to improve programs for businesses and hard-to-recycle materials around the State. There will be a published report, but your information will be confidential.
If you would prefer, we would be happy to complete the survey over the phone on our toll free number 866-XXX-XXXX.

Thank you for your help in this and please contact us with any questions,
Sincerely,

Lisa A. Skumatz, Ph.D.,
SERA Research
762 Eldorado Drive,
Superior, CO 80027

Appendix F: Summary of Values for Thermostat Ages and Lifetimes from Literature

Age Estimates of Thermostats on Walls, and Lifetimes of Thermostats

The authors conducted a review of the literature to examine two main topics around thermostat ages:

- the median estimated lifetime, and
- the average age of thermostats in place.

These results provide a context for the results for median lifetimes that the authors developed for Rhode Island (about 36 years) and Illinois / California (about 27.5 years). The Rhode Island study found the average age of mercury thermostats on the wall was 29.7 years and median was 28.5 years. Illinois study found the average age of mercury thermostats on the wall was 32.1, and the median was 31 years.

There is almost no data reporting average ages of thermostats on walls, and few statistical studies on their expected lifetimes. Figure 1 summarizes the literature identified in a web search. The literature does not suggest that the age of thermostats being taken out of service is significantly younger than our estimates. Our average and median are around 28-29 years old, and the expected lifetimes was 36 years. The table below shows:

- Average age of thermostats on walls: There are few studies addressing this question. The King County study provides data for a crude estimate of the age of commercial thermostats on the walls, and the estimate is 34.7 years.[51] The California study showed younger average ages of thermostats on the walls in California (about 30 years for round models, 21 for square). California differs in two ways from Illinois. It is a state with generally newer construction than Illinois, and California has been one of the most aggressive states in the nations for installing digital thermostats.
- Average lifetime for mercury-containing thermostats: The majority of the literature places the lifetimes of mercury (and presumably, traditional mechanical-type) thermostats at about 20-35 years.
- Average age for non-mercury, digital model thermostats: These studies are related to energy efficiency programs, and their lifespans are associated with digital models. These studies are commonly estimating 10-15 year lifetimes for digital models. These models are clearly not expected to last as long as the mercury models.

These figures we estimated in this report are reasonable, compared to the limited literature available.

[51] Based on a weighted average of the midpoint ages of thermostats from Table 4 of the report, Savina, "Mercury Thermostats in Commercial Buildings in King County", November 2005.

Figure 1: Average Ages, Lifetimes, and Expected Lifetimes for Thermostats, from the Literature
(assembled by Lisa A. Skumatz, Ph.D., and Dana D'Souza, Skumatz Economic Research Associates, April 2014)

Year	Type	Number described as…	Source
Average age of Thermostat Models on the Walls			
34.7 years	Com'l	Average age in commercial buildings currently	Savina, "Mercury Thermostats in Commercial Buildings in King County", 2005, calculation from classes of building / thermostat ages, from Table 4.
30.9 for round; 21.4 square	Res	Average ages of round and square mercury-containing thermostats in existing buildings	Skumatz, Lisa A., 2009, "Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings (California)", page 4; confidence intervals were also given
29.4 round; 21.9 square	Com'l	Average ages of round and square mercury-containing thermostats in existing buildings	Skumatz, Lisa A., 2009, "Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings (California)", page 4; confidence intervals were also given
Lifespan of Mercury Thermostat Models			
20-40 years	Not given	Lifespan of mercury switch thermostat	Leopold, Barry R., "Use and Release of Mercury in the United States", SAIC, for EPA National Risk Management Laboratory, EPA/600/R-02/104, December 2002, page 29.
30 years	Not given	Thermostat lifespan	Northeast Waste Management Official's Association (NEWMOA), "Review and Assessment of Thermostat Recycling Activities in the Northeast", June 2008, page 7, quoting from January 1999 report by Maine Land and Water Resources Council "Labeling and Collection of Mercury-Added Products, to the Joint Standing Committee on Natural Resources 119th Main Legislature".
30 years	Not given	Average life of mercury thermostats reported from EPA 2008	Cleanwater Action- Massachusetts Zero Mercury Campaign
35 years	Not given	Mercury-containing thermostats	California Health and Safety Code Section 25214.8.1 http://law.onecle.com/california/health/25214.8.1.html
35 years	Not given	Mercury-containing thermostat, referenced from New Hampshire 2010 report.	Maine Land & Water Resources Council; Labeling and Collection of Mercury Added Products report to Joint Standing Committee on Natural Resources, 119th Maine Legislature; January 1, 1999.
20-30 years	Not given	Designed lifespan mercury-containing thermostat, average replacement	MANITOBA STEWARDSHIP PLAN FOR MERCURY-CONTAINING THERMOSTATS Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI) with the support of the Canadian Institute of Plumbing and Heating (CIPH), 2010
30 years	Not given	Thermostat have a 30 year lifespan	A Plan to Improve the Collection of Mercury Thermostats, Maine Department of Environmental Protection, January 15, 2004 (Appendix 1). Excerpt found on http://mpp.cclearn.org
Lifespans, Unspecified, or Combination of Mercury and Non-Mercury (Digital) Models			
27.5 years	Both	Statistically-estimated expected useful lifetime (EUL) for thermostats	Skumatz, Lisa A., 2009, "Mercury-Containing Thermostats: Estimating Inventory and Flow from Existing Residential & Commercial Buildings (California)", page 19
35 years	Res	Thermostats are "usually replaced before the end of their 35 year lifespan due to technological improvements"	National Association of Home Builders/ Bank of America Home Equity Study of Life Expectancy of Home Components http://www.nahb.org/fileUpload_details.aspx?contentID=99359, 2007
35 years	Res	Standard estimated life expectancy for home	http://www.nachi.org/life-expectancy.htm International Association of Certified Home Inspectors

Year	Type	Number described as…	Source
		thermostats; 'Thermostats may last 35 years but they are usually replaced before they fail due to technological improvements.'	
Lifespans of Digital / New Install Thermostats			
11 years	Res	Life expectancy	ANSI / ACCA 12 QH – 2011 (Existing Home Evaluation and Performance Improvement), 2011[52]
8-11 years	Com'l	EUL for commercial setback / digital thermostats	California DEER Database, energy efficient measures
10-11 years	Res	EUL for residential setback / digital thermostats	California DEER Database, energy efficient measures
10-15	Not given	The average life for most thermostats is somewhere between 10 and 15 years, can be kept working over 20, but reliability diminished[53]	Frost & Sullivan, North American HVAC thermostat and Temperature Control Markets (May 2000).
Other Sources; not further specified			
20 years	Not given	Life expectancy. 20 (for controls: electric, electronic, and computer-direct digital); pneumatic 18 years.	Nominal Life Expectancy for Building Components http://www.menlofire.org/pdf/fca/06.%20Appendices/Appendix%204%20-%20Nominal%20Life%20Expectancy~.pdf No date specified; no further information / definitions
18, 17 years	Not given	Typical life expectancy controls: thermostat controls 17, heating programmed controller / timer 18 years.	Typical Life Expectancy of Building Components http://www.costmodelling.com/downloads/BuildingComponentLifeExpectancy.pdf

[52] NOTE: newer reports universally refer to newer, digital thermostat types. Their performance lifetimes have been expected to be shorter than traditional mechanical models (which are the ones that contain mercury).

[53] Likely again referring to digitals, given age of report and the consultant's work on energy efficiency programs, which promote and are concerned with digital models.