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# ***Estimated Annual Outflow of Mercury-Containing Thermostats in the State of Rhode Island***

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## ORGANIZATION OF REPORT

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# 1. Project Background and Executive Summary

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## ***Discussion of Rhode Island Law***

In 2010, the Rhode Island Legislature established a mandatory collection and recycling regime aimed at significantly improving the number of mercury thermostats previously collected under a voluntary manufacturer take-back program. The law requires heating, ventilation and cooling (HVAC) contractors or service technicians to recycle mercury-switch thermostats that are taken out of service, and requires thermostat manufacturers to pay for the transportation of the collected mercury-switch thermostats to an appropriate recycling facility. The law also establishes goals for the collection of mercury-switch thermostats in the first four years of the program, requires the Rhode Island Department of Environmental Management (RIDEM) to set the collection goals for 2015 to 2020, and authorizes RIDEM to mandate improvements to the collection programs if the goals are not achieved. Beginning in 2020, and every two years thereafter, RIDEM must report to the Legislature on whether the collection goals should be revised and/or whether the program should be terminated.<sup>1</sup>

To set the performance goals for the program beginning in 2015, RIDEM is required to consider, among other factors, any reports or studies on the number of out-of-service mercury thermostats that are available for collection in Rhode Island and other states. RIDEM must set the collection goals by November 1, 2014.

## ***Summary of the Project's Steps***

Under a contract to the Natural Resources Defense Council (NRDC) and the Multi-State Mercury Products Campaign (through the Clean Water Fund), 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 Rhode Island.<sup>2</sup>

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);
- Mailed several rounds of email notifications to the commercial sector sample to improve the statistical properties and increase the response count;

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<sup>1</sup> Additional information on the Rhode Island law can be found at <http://www.dem.ri.gov/programs/benviron/assist/thrmstat/>.

<sup>2</sup> This report represents the analysis and conclusions of SERA, not of NRDC or the Clean Water Fund.

- Analyzed the data gathered from the survey;
- Conducted an effort to validate and provide additional context for the survey responses to be used in the analysis, consisting of interviews with 12 HVAC (heating, ventilation, and air conditioning) contractors around the state to gather information on mercury-containing thermostats in buildings in the state;
- Conducted an effort to validate and provide additional context for the survey responses to be used in the analysis, by reaching out to a sample of respondents to request counts and photos of the installed thermostats to allow verification of the accuracy and consistency of responses regarding reporting of thermostat counts and types;
- 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 33 respondent premises 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 Rhode Island, which may be used to advise the establishment of State goals for mercury thermostat recycling program performance. The study analyzed information from 734 with thermostat responses, and the estimates show nearly 730 thousand (727,823) thermostats in place in Rhode Island (almost 260,000 with mercury). The number of mercury-containing thermostats flowing out of residential and commercial buildings in the state is approximately 8,000-11,000 annually over the next 10-15 years. Figure 1.1 provides a summary of the estimate of mercury- and non-mercury-containing thermostats currently on walls in the State of Rhode Island.

**Figure 1.1: Summary Statistics of Thermostat Results for Rhode Island**

Summary Results	Residential	Commercial	Total
Number of Households or Establishments (thousands)	462,564	28,181	490,745
Average Thermostats per Unit <sup>3</sup>	1.22	5.8	1.5
Number of Thermostats in place (thousands)	564,160	163,663	727,823
Percent of In-Building Thermostats containing Mercury	36%	36%	36%
Estimated Number of Mercury-containing thermostats in place (Thousands)	200,280	58,101	258,381

Figure 1.2 presents the summary of the estimated flow of thermostats off walls in the State of Rhode Island in five year groups (note the first grouping is six years). We present several estimates. The first two columns represent the estimates based on Rhode Island data. Analysis of the survey data from Rhode Island led to an estimate of an expected median lifetime for thermostats in the state of 36 years. When we compared this to the literature (specifically work in California, and recent work in Illinois), this estimate is considerably longer than the approximately 27.5 year median developed in those studies.

We incorporate both sets of information in our estimates of outflow rates for mercury thermostats in Rhode Island (presented in Figure 1.2). The first set of columns presents the annual estimates of outflows (for five and six year groupings) of mercury-containing thermostats off walls using the lifetime decay function estimated for Rhode Island. The second set of figures uses the same inventory totals for

<sup>3</sup> Approximate 90% confidence intervals for the means are, 1.08-1.36 for residential thermostats per household, and 4.46-7.14 for commercial thermostats per establishment.

Rhode Island, but calculates the annual outflows (again in five and six year groupings) using a thermostat decay function with an expected median lifetime of 27.5 years. These figures bracket the results. The estimated outflows are presented in Figure 1.2.

**Figure 1.2: Estimated Five Year Averages of Annual Outflows of Mercury-Containing Thermostats from Rhode Island**

5-6 Year Periods	Annual Flow & Percent Hg/Yr – Median Lifetime 36 Years		Annual Flow & Percent Hg/Yr – Median Lifetime 27.5 Years		Average of Estimates of Outflows
	Mercury-thermostats - avg. flow / year	Mercury Thermostats: Cumulative Percent flowed out	Mercury-Thermostats avg. flow / year	Mercury Thermostats: Cumulative Percent flowed out	Average of Median Life Outflow Estimates
2014-2019	8,900	21%	11,400	26%	10,150
2020-2024	9,800	40%	11,300	48%	10,550
2025-2029	12,000	63%	10,600	69%	11,300
2030-2034	7,900	78%	6,800	82%	7,350
2035-2039	4,500	87%	3,900	90%	4,200
2040-2044	4,600	96%	3,700	97%	4,150
2045-2049	2,200	100%	1,700	100%	1,950
2050-2054	0		0		0
Total to 2074	258,400		258,400		258,400

As Figure 1.2 indicates, only about a quarter or less of the mercury thermostats still in use in Rhode Island will become available for collection when RIDEM must begin considering whether the program should be terminated in 2020.

The figures presented in this report are conservative, because:

- The lower of un-weighted and weighted averages for the percent of each type of thermostat that contains mercury was used;
- An adjustment factor (increase of 20%) correcting for under-reporting of potentially mercury-containing models was not incorporated;
- We exclude thermostats in common areas of apartment buildings and some commercial buildings; and
- The number of thermostats reported by households was reduced in alignment with field and validation inspections carried out to validate the survey responses.

## **Background and Context**

A number of states are passing mandatory mercury thermostat collection laws and associated 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.

## ***Background on the Literature***

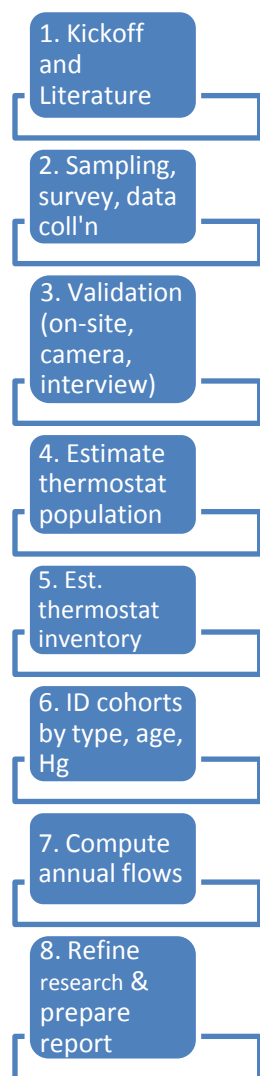
Three existing studies were reviewed in the preparation of this research study. A more detailed review of the literature is provided in Appendix A.

- 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 Rhode Island estimation work, we conducted a multi-step analysis very similar to work conducted concerning thermostats in Illinois, and with core similarities to the California DTSC study. The study incorporated some revisions reflecting peer review of the California study. The analysis consisted of the following steps:

**Figure 1.1: Summary of Research Steps**



- 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 other useful background information.<sup>4</sup>
- Validation and research efforts:** Conduct in-field validation and research work, including three efforts. 1) 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 potentially age/ other information (this effort was conducted by Clean Water Fund, Rhode Island, with SERA providing the sample to be surveyed); 2) by phone and email, request photos of all thermostats in place in a random set of survey respondent locations to verify the “count” and types of thermostats compared to survey responses; and 3) conduct interviews with a sample of Rhode Island HVAC contractors to better understand thermostat installation and removal practices (current and historical), and 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.
- 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.

- Compute Existing Thermostat Population on Walls:** Use survey data to estimate the average number of thermostats in place in residences<sup>5</sup>, and multiply by the number of residences to compute the total number of residential thermostats in homes. Use appropriate sample

<sup>4</sup> Note that the survey was presented or distributed to the sample as a ‘recycling and hard-to-recycle’ survey, and included simple questions about standard household or business recycling first. The survey was presented to respondents in this way to achieve two aims: 1) to try to get higher responses than might be achieved if it was presented as a thermostat survey (thermostat questions may not be perceived as interesting or as easily answered to most respondents as questions about traditional recyclables); 2) to try to ensure that we received responses from households (or businesses) without thermostats, who might elect not to engage in a survey presented as concentrated on thermostats.

<sup>5</sup> Including buildings with zero thermostats.

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.<sup>6</sup>

- **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 that 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 Clean Water Fund, Rhode Island, augmented with input from the contractors.
- 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 thermostat inventory in place in the field: from the web survey responses stating the best estimate of the year that existing cohorts of mercury-containing thermostats were installed, 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.*

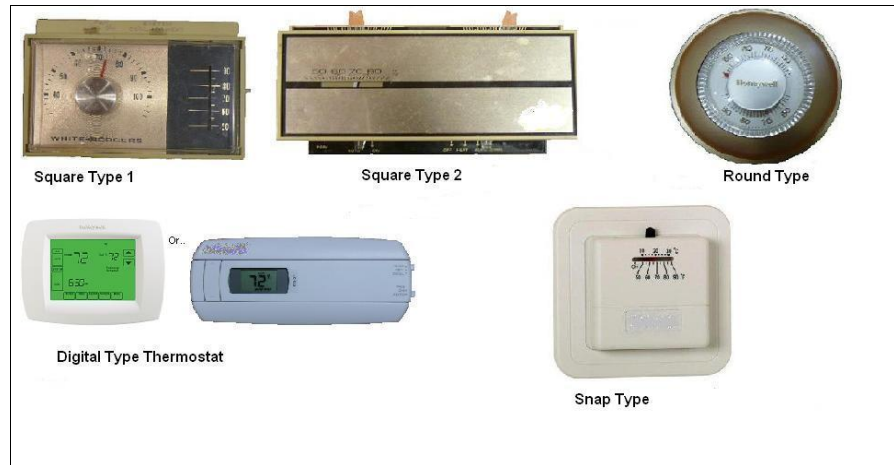
One additional complexity was introduced in order to provide more refined estimates; however, the computation methods remain essentially the same. Rather than asking about “wall thermostats” in general, the survey and validation work asked about specific subgroups of thermostats. They are illustrated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

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<sup>6</sup> The computation of the percent that are mercury takes place in a later step in this discussion.



- Digital
- Round
- Square (not digital)
- Lever
- Snap
- Other



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 replicated industry typology used in the SERA / DTSC / TRC study, allowing leveraging of information.

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 peer review comments on the approaches, and conducting an assessment of the strengths and weaknesses of the alternatives (relative to reasonable budget constraints).<sup>7</sup> This is a strong approach, with good performance demonstrated in the confidence intervals and “fit” statistics for the model, as outlined below. Evaluation is designed to provide information to guide better decision-making, and the estimates included are defensible and support program design and goal-setting applications; the sample sizes were strong.

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<sup>7</sup> 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.

## 2. Conducting Steps A & B: Deriving an Estimated Inventory / “Count” of Mercury-Containing Thermostats in Rhode Island Buildings

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**Population and Sample:** The survey was based on a purchased sample.<sup>8</sup> To represent the residential sector, a simple random sample of residential and multi-family addresses across the State was purchased. Our implicit assumption was that 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 homes<sup>9</sup>, so a random sample design would suffice.

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 of number of employees at the establishment. There are many small businesses, but they are likely to be similar to each other (in thermostat presence and lifetimes); 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 to reflect square footage, a variable we *did* expect to have an effect on at least the number of thermostats at the site. We purchased a random sample of each of four business sizes (less than 20 employees, 20-99, and 100 and more employees). 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 Rhode Island, we actually purchased all of the names for the larger two business categories. This stratification technique can improve the quality and robustness of the database.

Figure 2.2 later in this chapter shows the sample sizes per group, response rates, and estimated “counts”.

**Survey Approach:** Users called up 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 with small businesses),
- It can be distributed easily and 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

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<sup>8</sup> Purchased from InfoUSA, a well-known vendor.

<sup>9</sup> 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.

analyzed in “real time” and the survey “left active” and analyzed again when more responses have been received.

The survey was distributed via postcard to the sampled homes and businesses, providing a link to a web survey (on SERA’s neutral website “garbageandrecyclingsurvey.com”), with two email follow-ups to the business sample, as their response rate had lagged. 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). The postcard and emails also notified recipients that filling out the survey entered them into a lottery to win one of several Kindles<sup>10</sup>.

**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 match 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 thermostats in buildings.
- Type of thermostats (we included photos of various types, and asked respondents to classify thermostats into square, round, snap, digital, or lever or other, as shown in the photo in the executive summary).
- How many thermostats in buildings of the type(s) of interest; whether each is still functioning (&)<sup>11</sup>
- Year built (\*); best estimate of year thermostats were installed, and, if any were removed, when removed.
- 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 and/or income.
- Firmographic data: type of business, estimated square footage, number of employees.

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

**Sample Size:** Getting sufficient respondents is generally a problem with surveys (and general survey confidence levels associated with variations in response are listed in the table below), 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<sup>12</sup> is not very different. No matter how big the total households (within a fairly large band), the sample sizes needed are similar.<sup>13</sup> However, samples sizes for EUL surveys are an especially large

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<sup>10</sup> 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.

<sup>11</sup> 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.

<sup>12</sup> 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 benchmark for higher vs. lower accuracy sample sizes.

<sup>13</sup> This is why Nielsen television ratings or Gallup election polls can use nationwide samples of 1200 and get accuracy nationwide.

problem. General responses are satisfactory for the inventory portion of the project, but to estimate lifetimes and turnover, you need “failures and removals”, which happen in (or are known about in) only a portion of the responding businesses and homes. We obtained more samples to assure we have enough that failed / were removed. Generally, however, more data (rather than less) help predictive modeling work.

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

IF the community’s population (homes or comm’l bldgs) is...	95% confidence		90% confidence	
	+/-5%	+/-10%	+/-5%	+/-10%
Computed responses needed for accuracy of...				
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. The Rhode Island survey responses received – 504 residential (with thermostat data) and 230 commercial – provides accuracy levels of, respectively, +/-4.4% and 6.4% at the 95%<sup>14</sup> confidence level. These response counts are within the level usually considered strong for analytical work of this type.

After comparing the response rates by county to census data in Figure 2.2 (to confirm that we received responses that were reasonably representative of the State), we estimated the “average” number of thermostats for each respondent type, as shown in Figure 2.3 (single family, multifamily, and the commercial strata). 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 Rhode Island. 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 2.2: Sample Size, Responses, and Estimated “Count” of Thermostats on Rhode Island Walls**

Category	RI Sample Purchased	RI Responses with # Therm	Response Percent of Purchased Sample
SF HHs (Grp1)	9,779	447	4.6%
MF HHs (2)	2,221	57	2.6%
Bus <=19 (3)	7,868	168	2.1%
Bus 20-99 (4)	3,435	49	1.4%
Business 100+	697	13	1.9%
Res Total	12,000	504	4.2%
Com'l total	12,000	230	1.9%
Grand Total	24,000	734	3.1%

<sup>14</sup> Also equals +/- 3.7 and +/-5.4% at 90% confidence level, respectively.

**Figure 2.3 Computation of Estimated Inventory of Thermostats on Rhode Island Walls**

Category	Census units & establishments	Number of Thermostats, Average by Class	Estimated Total thermostats in RI buildings
SF HHs (Group1)	274,300	1.42	388,661
MF HHs, per unit(Group ) <sup>15</sup>	188,264	0.93	175,499
Bus <=19 (Group 3)	22,742	3.55	80,692
Bus 20-99 (Group 4)	3,804	8.34	31,738
Business 100+ (Group 5)	1,634	31.35	51,233
Res Total	462,564	1.22	564,160
Com'l total	28,181	5.81	163,663
Grand Total	490,745	1.48	727,823

To provide a context for the results from the Rhode Island work, we benchmark the findings with the most comparable work available in the literature – the results from the 2009 California study (SERA 2009)<sup>16</sup> and the Illinois study (SERA 2014)<sup>17</sup>. The comparison in Figure 2.4 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. We also compared the available outflows of mercury-containing thermostats in the next 6 years for Illinois, California, and Rhode Island. 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.

**Figure 2.4 Comparison of Rhode Island Results to Findings from Similar Studies in the States of Illinois and California (SERA, 2014, 2009, respectively)**

Comparison of Thermostat Inventories on Walls	Rhode Island	Illinois	California
Average Number of Thermostats			
Per Household	1.22	1.15	1.17
Per Business	5.81	5.16	5.6
Overall (weighted average of households and businesses)	1.48	1.38	1.5
Total Thermostats in State (thous)	728	7,700	19,800
State Population (thous)	1,051	12,900	38,000
Thermostats per Capita (therm/pop)	0.69	0.60	0.52
Comparison of Annual Outflow Estimates	Rhode Island	Illinois	California <sup>18</sup>
Mercury Thermostats per year, average for 2014-2019	8,900-11,400	102,000	199,700
Mercury flow / population * 10,000	85-108	79	101

<sup>15</sup> Excludes thermostats in common areas of multi-family buildings. We only asked about thermostats inside the individual dwelling units.

<sup>16</sup> 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.

<sup>17</sup> 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.

<sup>18</sup> Based on outflow estimates for 2014-2019 generated by SERA and adopted by the California Department of Toxic Substances Control in its performance standards rulemaking. See

[http://www.dtsc.ca.gov/LawsRegsPolicies/Regs/upload/Text\\_-\\_Mercury-Thermostat\\_05\\_14\\_13.pdf](http://www.dtsc.ca.gov/LawsRegsPolicies/Regs/upload/Text_-_Mercury-Thermostat_05_14_13.pdf).

## 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:** Clean Water Fund, Rhode Island sent trained staff to complete on-site visits to a set of specially selected respondent buildings (residential and commercial) as possible. They completed on-sites at 33 survey respondent sites (residential and commercial).<sup>19</sup> Their trained staff inspected thermostats to determine whether they contained mercury or not, and checked whether the sample of survey respondents were accurate in their report of the number and type of thermostats in their home or establishment. Clean Water Fund Rhode Island staff photographed thermostats to document the presence of mercury in the thermostats. SERA selected the sample from among buildings that responded to the survey (residential and commercial, randomly selected within geographic clusters<sup>20</sup> to manage travel costs). This provided valuable information and ‘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 19 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.<sup>21</sup> In return, for those sending in photos, gift certificates to Starbucks were sent. The camera validations reconfirmed 130 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 interviewed a sample of 12 Rhode Island HVAC contractors around the state. 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

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<sup>19</sup> The on-site validation sample included buildings in the following communities: Newport, Narragansett, Charlestown, Warwick, West Warwick, Providence, North Providence, Barrington, Bristol, Warren, Jamestown, Little Compton, Tiverton, Smithfield, Gloucester, North Kingstown and Cranston.

<sup>20</sup> 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.

<sup>21</sup> The camera-phone validation sample included buildings in the following communities: Coventry, Cranston, East Providence, Johnston, Kingstown, Newport, North Scituate, Pawtucket, Providence, Rumford, Saunderson, and Warwick. The camera validation allowed us to confirm classifications, and check the consistency of the count of thermostats on the walls.

Figure 2.5 tabulates the results of the on-site validations by Clean Water Fund, Rhode Island of the percent of thermostats inspected that contained mercury. The samples sizes for the on-site mercury inspections are moderately strong (at least on the commercial side). We elected to use the commercial sector estimates across the board, rather than applying the small-sample residential values.<sup>22</sup> When weighted by “type” based on the survey responses, the overall percent of mercury-containing thermostats on walls in Rhode Island is estimated to be 34% (see Figure 2.8). When asked about the percent of all thermostats in place on walls that contained mercury, the (limited) sample of contractor reported that had a range of 4-50% overall, and our estimate is a little higher than the middle of that range.

**Figure 2.5: On-Site Validation Results: Percent of Thermostats Containing Mercury, by Type**

On-site Validations	Commercial On-site	Residential on-site	Weighted Average (78% resid'l, 22% com'l)	Simple Average
Square: % with Mercury (19 inspected)	64%	80%	76%	72%
Round: % with Mercury (26 inspected)	96%	100%	99%	98%
Digital: % with Mercury (91 inspected)	0%	0%	0%	0%
Snap: % with Mercury (2 inspected)	0%	0%	0%	0%
Lever / Dial / Other: % with Mercury (0 inspected)	n/a	n/a	n/a	n/a

The results show that the largest share of mercury-containing thermostats on Rhode Island walls are of the round and square types. Based on these results, the total thermostats that are mercury-containing were estimated somewhat conservatively<sup>23</sup> using the less of the weighted and simple averages from above:

- 72% of total estimated square models are assumed to contain mercury;
- 98% of round thermostats are assumed to contain mercury;
- 0% of other types of thermostats (snap, lever / dial, and digital models) are assumed to contain mercury;
- No thermostats installed since 2006 (less than 8 years old) are assumed to contain mercury.<sup>24</sup>

### Validation Findings on Survey Counts

Figure 2.6 compares the total number of thermostats that a sample of business and household respondents provided on the survey. Some of the sample counts from the sample were verified during the on-site work, and others were validated by the camera validation approach. The results show that the total counts from the validation work were fairly close to those reported in the survey; however, households tended to include some other equipment in their count (including controllers for fans), and commercial buildings underestimated their thermostat totals. Two correction factors were used to

<sup>22</sup> This parallels the conservative approach used for previous work in Illinois (SERA 2014); in that study, estimates of 70% for square and 95% for square were used to represent the mercury share of these thermostat types.

<sup>23</sup> 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.

<sup>24</sup> The data saw a 2% reduction in the total mercury-containing thermostats that had ages reported when those newer than 5 years were removed.

bring commercial and residential thermostat counts into agreement with the verified totals. Overall, verified counts were within about 10% of the totals reported in the survey. This correction factor is applied in the computation of corrected totals in Figure 2.7 below.

**Figure 2.6: Validation Results on Total Count of Thermostats, Total and by Thermostat Type**

	Residential	Commercial	Combined, weighted
Number of thermostats reported by survey	39	191	
Number of thermostats found in on-site and camera validations	31	238	
Resulting "adjustment" factor for totals (combined is weighted by prevalence of residential vs. commercial)	79%	125%	90%

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 2.7) suggests that the mis-assignment of mercury thermostat types could justify an increase of about 20% for the estimate of mercury-containing models. Because of the relatively small sample on which these figures are based, and in an effort to be conservative, we omit this correction factor. The combinations of adjustments are addressed in the corrected totals in Figure 2.9. Graphics of the survey responses on types of thermostats in residential and commercial buildings in Rhode Island are presented in Figure 2.10.

**Figure 2.7: 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	78
Number of mercury-containing thermostats from camera and on-site validation, same sample	94
Resulting potential "adjustment" factor for totals	1.21

**Figure 2.8: Calculation of Inventory of Mercury-Containing Thermostats in Buildings in Rhode Island, absent correction factors**

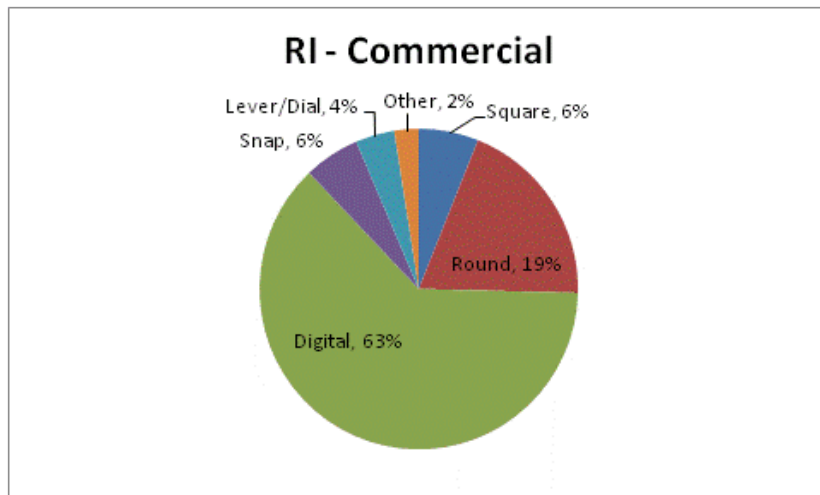
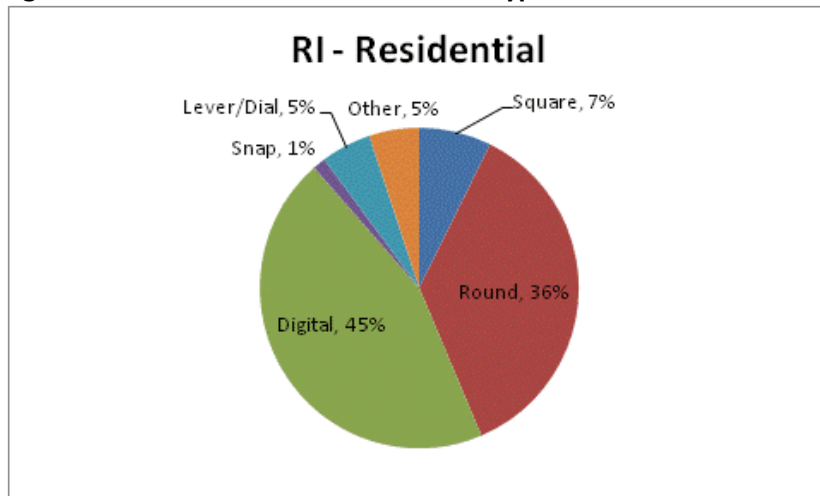
Percent by Thermostat Type and Building Type	Square	Round	Digital	Snap	Lever/dial	Other	Total Thermostats (thous)
SF HHs (Grp1)	7%	36%	45%	1%	5%	5%	388,661
MF HHs (2)	12%	41%	31%	2%	7%	7%	175,499
Bus <=19 (3)	6%	31%	50%	7%	2%	4%	80,692
Bus 20-99 (4)	5%	18%	59%	1%	16%	0%	31,738
Business 100+	6%	2%	85%	6%	0%	1%	51,233
Res Total	49,477	212,867	228,069	8,369	32,689	32,689	564,160
Com'l total	9,881	31,670	102,397	9,244	6,438	4,033	163,663
Grand Total	59,358	244,537	330,466	17,613	39,127	36,722	727,823
Percent with Mercury (computed from on-site visit inspections, Figure 2.5, selected averages)	72%	98%	0%	0%	0%	0%	39%
Total Mercury Thermostats (thousands)	42,738	239,646	0	0	0	0	282,384
Percent Mercury ==>							39%



**Figure 2.9: Adjustments to Mercury Thermostat Counts, and Revised Total, Rhode Island (thousands)**

Potential Adjustments	Initial (Figure 2.8)	Mis-reporting total number of thermostats vs. validation; 79%/125%/90% (Fig 2.6)	Under-report Hg Types; add 21% (Fig. 2.7)	Re-classify all reported Hg Thermostats 8 years or younger (8.5%) to non-Hg	Revised totals
Estimated Mercury-Containing Thermostats (Figure 2.8)	282,384	254,146	341,685	258,381	258,381
Estimated Non-Mercury Thermostats	445,439	400,895	386,139	469,442	469,442
Estimated Total Thermostats	727,823	655,041	727,823	727,823	727,823
Mercury Percent of Total	39%	39%	47%	36%	36%
Decision	Base Figure	Not invoked; both directions	Not invoked to be conservative	Invoked	Revised

**Figure 2.10: Distribution of Thermostat Types in Residential and Commercial Buildings in Rhode Island**



### 3. Conducting Steps C & D: Estimating the Flow of Mercury-Containing Thermostats from Rhode Island 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 Rhode Island 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.<sup>25</sup>

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”. The selected Gamma-based model performed best on the basis of a comparison of log likelihood statistics. 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 36 years; that is, half the thermostats installed are would be expected to still be in place and functioning 36 years *after installation*, and the other half would have been removed. This is a substantial difference from the 27.5 year median life results obtained in the California and Illinois studies.<sup>26</sup> Thus, we provide the estimates of outflow using the Rhode Island decay or lifetime function, and using the Illinois<sup>27</sup> decay function, the most recent other work.

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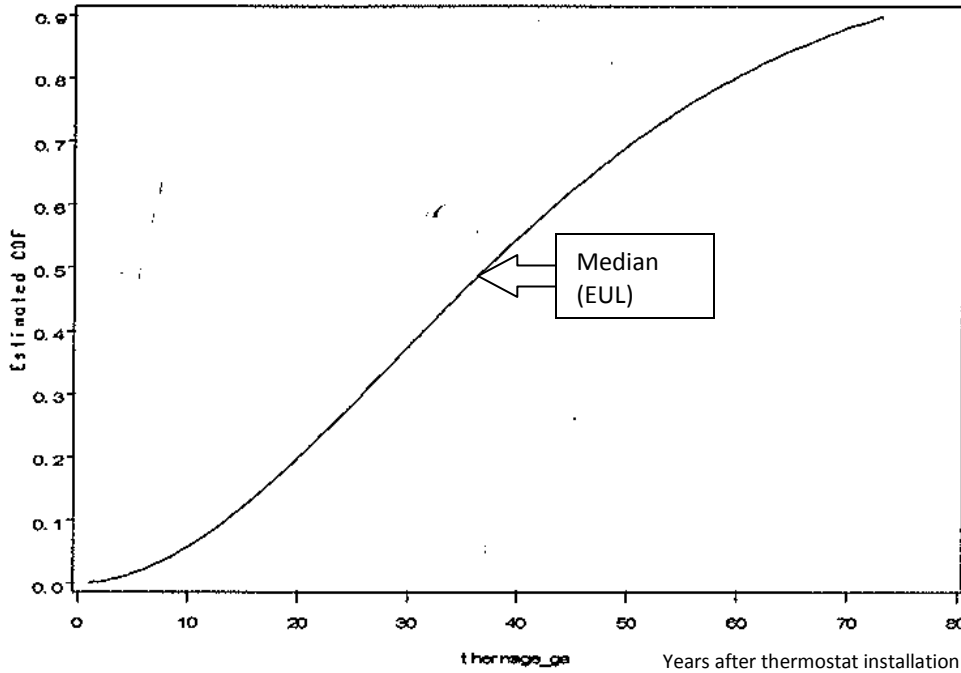
<sup>25</sup> Step “D” clarifies the refinement needed to this last statement to obtain the final annual estimate.

<sup>26</sup> SERA 2010, SERA/NRDC 2014, respectively.

<sup>27</sup> 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 Failed / Removed by Age of Thermostat – For One Cohort of Thermostats**

Cumulative Share of thermostat failing / removed



*(vertical axis is share of thermostats failed, 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 Thermostats on the Wall, by Percentiles (5% increments)**

Percentile Groupings	Age in years for Mercury-Containing (RI)	Age in years for Non-Mercury-Containing (RI)
1% of thermostats	9.0	2.0
5% of thermostats	11.0	2.0
10% of thermostats	13.0	2.0
15% of thermostats	15.0	2.0
20% of thermostats	17.5	2.0
25% of thermostats	21.5	2.0
30% of thermostats	23.5	2.0
35% of thermostats	24.5	2.0
40% of thermostats	26.5	5.0
45% of thermostats	27.5	5.0
50% of thermostats (median)	28.5	7.0
55% of thermostats	29.5	7.0
60% of thermostats	30.5	9.0
65% of thermostats	31.5	9.0
70% of thermostats	34.5	11.0
75% of thermostats	38.5	12.0
80% of thermostats	48.5	13.0
85% of thermostats	50.5	15.0
90% of thermostats	55.5	21.5
95% of thermostats	58.4	31.5
99% of thermostats	73.5	48.5
Average (mean) of thermostats currently on walls in Rhode Island	29.7	9.2

The actual computation of annual flows of mercury-containing thermostats from Rhode Island 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”, based mainly on type (98% of round, 72% of square were mercury). Second, we classified all thermostats with ages less than eight years as non-mercury, since mercury models were banned in 2006. Then we divided the total inventories of existing mercury and non-mercury thermostats into cohorts based on 5% groupings (a finer distinction than “quartiles”)<sup>28</sup>, ranked by age of the thermostats currently installed.<sup>29</sup> The figures,

<sup>28</sup> We ultimately modeled the flows based on quartiles representing every 5% of the thermostats; 5%, 10%, 15%, etc. This helped “smooth” the flows considerably, compared to using batches representing 25% of thermostats.

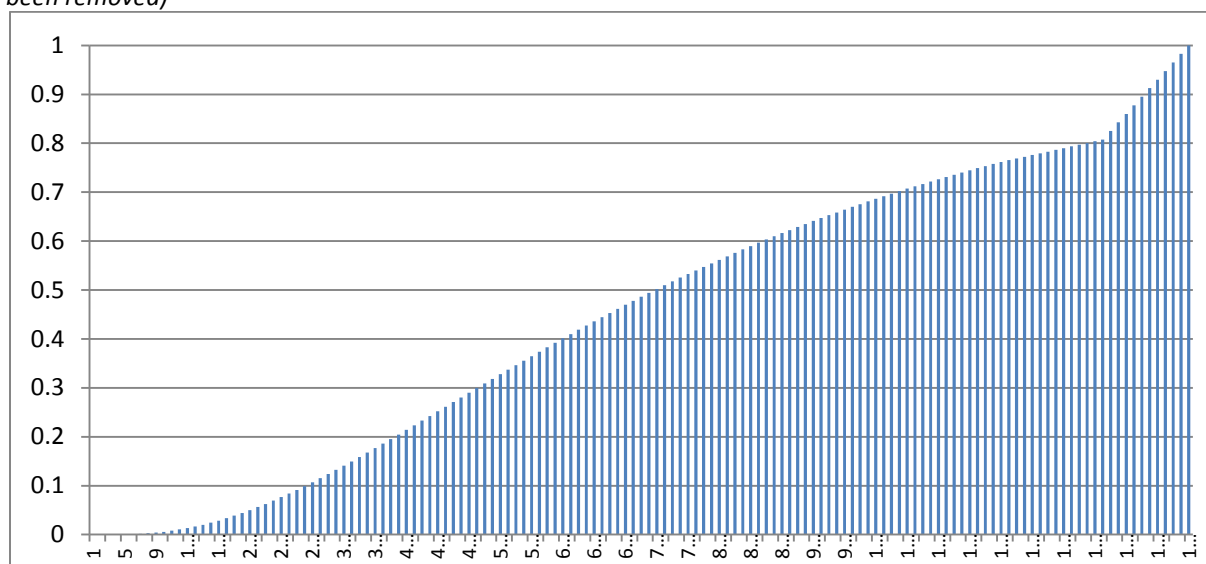
<sup>29</sup> We excluded digital thermostats because 1) they do not contain mercury, and 2) they are newer and would have skewed the quartiles toward “newer” equipment, and biased the flows downward. Mercury containing thermostats tend to be older equipment and may be expected to flow out at a faster rate than we would estimate if digital models were left in the computations.

displayed in Figure 3.3, show that the youngest 25% of mercury-containing thermostats are about 21 years old, but the youngest quarter of non-mercury-containing models were less than 5 years old. The average age of mercury-containing models on the wall is 29.7 years (median, or half, are 28.5 years or older). For non-mercury-containing models, the average age is 9.2 years, and the median is 7 years old. Note, this is distinct from the median age expected for lifetimes for thermostats, which is the 36 year or 27.5 year figure referred to in Figure 1.2. 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.

Using the bar chart approximation to the fitted lifetime curve (Figure 3.3), we started at the years of life already expended, and adjusted the annual disposal streams for each cohort to conform with expecting 100% of the models to expire at about 70 years. Several of the cohorts were completely collected in the 25 years we show on the table (the cohort with 54 year old equipment or higher). We summed up the cohorts to develop the estimate of the total market that would flow out in a given year.<sup>30</sup> The estimated results are presented in Figure 3.4 and are shown graphically below.<sup>31</sup>

**Figure 3.3: Excel™ approximation to the Measure Life Distribution Function**

*(the horizontal axis is ½ years; the vertical axis represents the cumulative share of thermostats that have failed or been removed)*



Notice that the outflows in Figure 3.4 below do not monotonically decrease over time; there are increases and decreases. There are two causes for this result. 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. We see “bulges” in the number of thermostats with close ages. Figure 3.2 clearly shows that large proportions of the thermostats on the wall are reported to be between 21 and 27.5 years of age (a quarter of the thermostats). Another 20% are between 28.5 and 34.5 years of age. These cohorts then cause surges in

<sup>30</sup> Based on lifetime expectations, not including adjustments for temporary economic circumstances.

<sup>31</sup> The Excel approximation to the estimated model formula varies slightly at the outer years to make the function get to 100%.

outflows some years later. We see a bulge in the outflows in year 2023 in Figure 3.4, for instance. The bulge in installations 20-27 years indicates an increase in building in the late 1980s and 1990s; this seems to match the timing of the late 1980s / 1990s housing booms (and declines) shown in Figures 3.5 and 3.6 below.

The annual results from these computations are provided below, in Figure 3.4. The estimate provided in the Executive Summary is computed from the five year averages from this table, presented below as Figure 3.7.

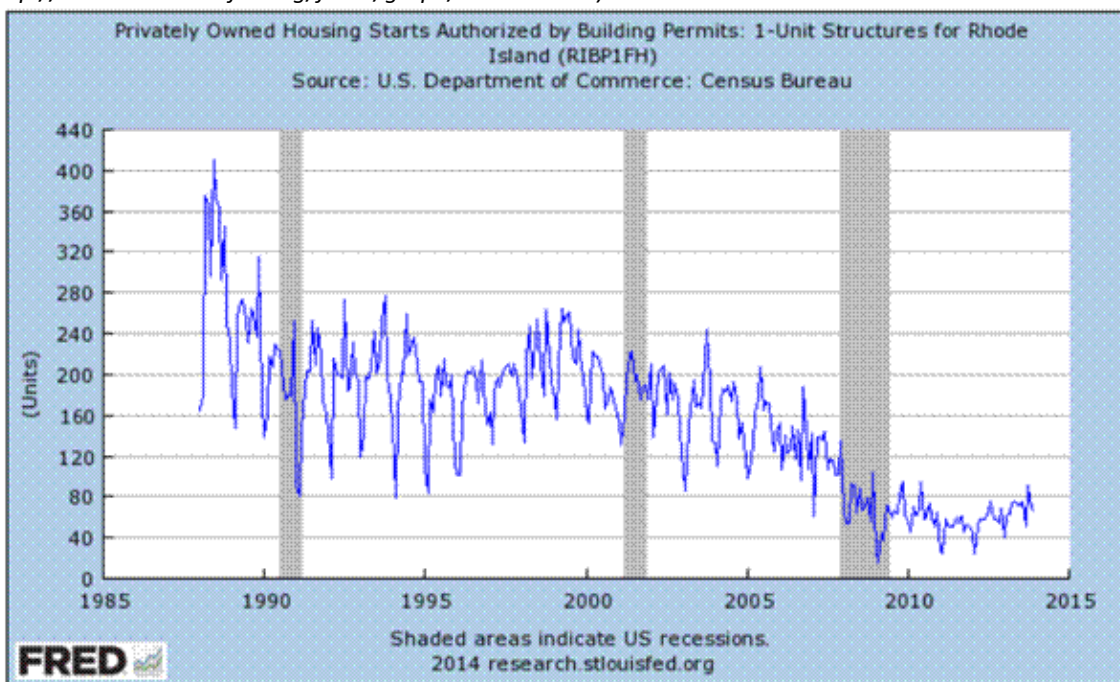
**Figure 3.4: Annual Flow of Rhode Island Mercury-Containing Thermostats assuming Multiple 5% Cohorts of Mercury-Containing Thermostats**

Year	Mercury-containing thermostat outflow, by year	Cumulative Percent of Mercury Models Removed
2014	9300	4%
2015	9200	7%
2016	9100	11%
2017	8800	14%
2018	8600	17%
2019	8600	21%
2020	8500	24%
2021	8300	27%
2022	8100	30%
2023	10700	35%
2024	13200	40%
2025	13100	45%
2026	13000	50%
2027	12900	55%
2028	13500	60%
2029	7400	63%
2030	8000	66%
2031	8500	69%
2032	8400	72%
2033	8300	76%
2034	6200	78%
2035	6100	80%
2036	4200	82%
2037	4100	84%
2038	4000	85%
2039	3900	87%
2040	4300	88%
2041	4700	90%
2042	4600	92%
2043	4400	94%
2044	4800	96%

Year	Mercury-containing thermostat outflow, by year	Cumulative Percent of Mercury Models Removed
2045	5100	97%
2046	3800	99%
2047	4100	100%
2048	0	100%

**Figure 3.5: Privately-Owned Housing Starts Authorized by Building Permits: 1-Unit Structures for Rhode Island**

(source: Economic Research by the Federal Reserve Bank of St. Louis; on-line Newsletter, undated, website <http://research.stlouisfed.org/fred2/graph/?id=RIBP1FH>)



**Figure 3.6: Residential Building Permits in Rhode Island, Annual (Number of buildings and housing units).** (Source: Census, <http://censtats.census.gov/bldg/bldgprmt.shtml>)

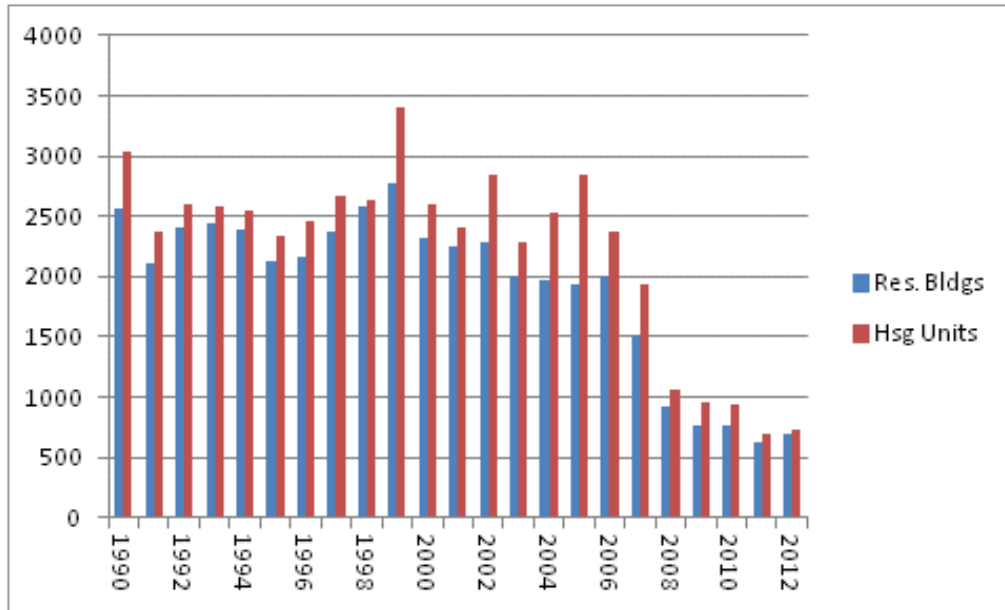


Figure 3.7 presents the summary of the estimated flow of thermostats off walls in the State of Rhode Island in five year groups (note the first grouping is six years). We present several estimates. The first two columns represent the estimates based on Rhode Island data. As mentioned earlier, analysis of the survey data from Rhode Island led to an estimate of an expected median lifetime for thermostats in the state of 36 years. When we compared this to the literature (specifically work in California, and recent work in Illinois), this estimate is considerably longer than the approximately 27.5 year median developed in those studies.

To provide a bound for the flow estimates, we computed five-year outflow projections based on both the Rhode Island decay curve (with its 36 year median life) and a decay curve consistent with a 27.5 year median thermostat lifetime. Both of these estimates are provided below. The first group of columns presents results using a 36 year expected median lifetime for thermostats; the second group of columns presents the annual outflow estimates based on a 27.5 year lifetime. In each case, we use the number and age distribution of Rhode Island thermostats on the walls. These figures bracket the results, and the last column presents the average of the two computations.



**Figure 3.7: Estimated Five Year Averages of Annual Outflows of Mercury-Containing Thermostats from Rhode Island**

5-6 Year Periods	Annual Flow & Percent Hg/Yr – Median Lifetime 36 Years		Annual Flow & Percent Hg/Yr – Median Lifetime 27.5 Years		Average of Estimates of Outflows
	Mercury Thermostats - avg. flow / year	Mercury Thermostats: Cumulative Percent flowed out	Mercury Thermostats avg. flow / year	Mercury Thermostats: Cumulative Percent flowed out	Average of Median Life Outflow Estimates
2014-2019	8,900	21%	11,400	26%	10,150
2020-2024	9,800	40%	11,300	48%	10,550
2025-2029	12,000	63%	10,600	69%	11,300
2030-2034	7,900	78%	6,800	82%	7,350
2035-2039	4,500	87%	3,900	90%	4,200
2040-2044	4,600	96%	3,700	97%	4,150
2045-2049	2,200	100%	1,700	100%	1,950
2050-2054	0		0		0
Total to 2074	258,400		258,400		258,400

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

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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.<sup>32</sup> 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.

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<sup>32</sup> 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
<b>On-site inspection &amp; analysis</b>	<ul style="list-style-type: none"> <li>• Reliably observed data</li> <li>• Can collect data for both steps 1 and 2 at the same time.</li> <li>• Provides robust data for projecting changes in thermostat removal over time</li> <li>• Can identify share that is residential vs. commercial if needed</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively expensive and labor intensive to obtain sample large and diverse enough for robust statistical reliability</li> <li>• Must identify suitable “population list,”<sup>33</sup> to sample from; design sample, and check / control for potential non-response bias</li> <li>• Analysis is somewhat complex</li> </ul>
<b>Occupant survey responses &amp; analysis</b>	<ul style="list-style-type: none"> <li>• Data collected based on on-site inspection of equipment; reasonable, but not infallible data</li> <li>• Can collect data for both steps 1 and 2 at the same time.</li> <li>• Provides robust data for projecting changes in thermostat removal over time</li> <li>• Can identify residential vs. commercial sources if needed</li> <li>• Fast to collect/get responses</li> </ul>	<ul style="list-style-type: none"> <li>• Less expensive than on-site data collection, but still requires significant resources</li> <li>• Must identify suitable “population list,” design sample, and check / control for potential non-response bias</li> <li>• Analysis is somewhat complex</li> </ul>
<b>Sales data</b>	<ul style="list-style-type: none"> <li>• Easy analysis</li> <li>• Relies on industry supplied data and expert judgments</li> </ul>	<ul style="list-style-type: none"> <li>• Extrapolating national sales/shipment data to a statewide basis does not account for state-specific conditions (e.g., age of building stock, climate, etc.)</li> <li>• Requires purchase of industry report on periodic basis, which requires funding.</li> <li>• Does not provide data for projections over time</li> <li>• Data sources are incomplete (not all firms “report”)</li> <li>• No data to support step 2</li> </ul>
<b>Contractor Surveys</b>	<ul style="list-style-type: none"> <li>• Use of “expert” knowledge</li> <li>• Relatively easy to obtain “sample” of contractors from purchased data, Better Business Bureau, etc.</li> <li>• Can concurrently collect information to support Step 2 (percent that contain mercury)</li> </ul>	<ul style="list-style-type: none"> <li>• Very weak response rates, even when partnering with industry associations; poor sample size</li> <li>• Busy, hard to contact, “varied” knowledge and experience; some opinions don’t “jibe” with numbers.</li> </ul>

**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

<sup>33</sup> 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.

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 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.<sup>34</sup> 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.<sup>35</sup>

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<sup>34</sup> 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.

<sup>35</sup> 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.

### 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 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,<sup>36</sup> *North American HVAC Thermostat Markets*, by Frost & Sullivan<sup>37</sup>. 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).

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<sup>36</sup> These reports are updated periodically and must be purchased from Frost & Sullivan. The 2003 report was the latest report available to government agencies.

<sup>37</sup> 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>.

- Occupant survey / reports (e.g., Skumatz / NEMA<sup>38</sup> report), and
- Contractor surveys.

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

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

Option	Strengths	Weaknesses
<b>On-site inspection</b>	<ul style="list-style-type: none"> <li>If conducting Step 2 using this method, data for Step 1 can be collected at the same time.</li> <li>Same pros and cons as Table 2.</li> </ul>	<ul style="list-style-type: none"> <li>Same pros and cons as Table 2</li> <li>Requires qualified staff able to remove covers and inspect units</li> </ul>
<b>Occupant survey</b>	<ul style="list-style-type: none"> <li>If conducting Step 2 using this method, data for Step 1 can be collected at the same time.</li> <li>Same pros and cons as Table 2.</li> </ul>	<ul style="list-style-type: none"> <li>Same pros and cons as Table 2</li> <li>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.</li> </ul>
<b>Contractor survey</b>	<ul style="list-style-type: none"> <li>Straightforward estimates of share of mercury-containing thermostats can be computed from data collected on total thermostats removed and number containing mercury.</li> </ul>	<ul style="list-style-type: none"> <li>Must identify suitable “population” list, design sample, and check / control for non-response bias</li> <li>Generally does not provide data to help estimate how the share of thermostats that contain mercury changes over time<sup>39</sup>.</li> </ul>

#### 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.<sup>40</sup> 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

<sup>38</sup> 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

<sup>39</sup> One can gather data to address this issue or surveys can be performed periodically to update the data (for goal-setting into the future).

<sup>40</sup> 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.

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).<sup>41</sup>

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.<sup>42</sup>

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<sup>41</sup> The author of this Rhode Island study (Skumatz) also served as an advisor on this PSI research.

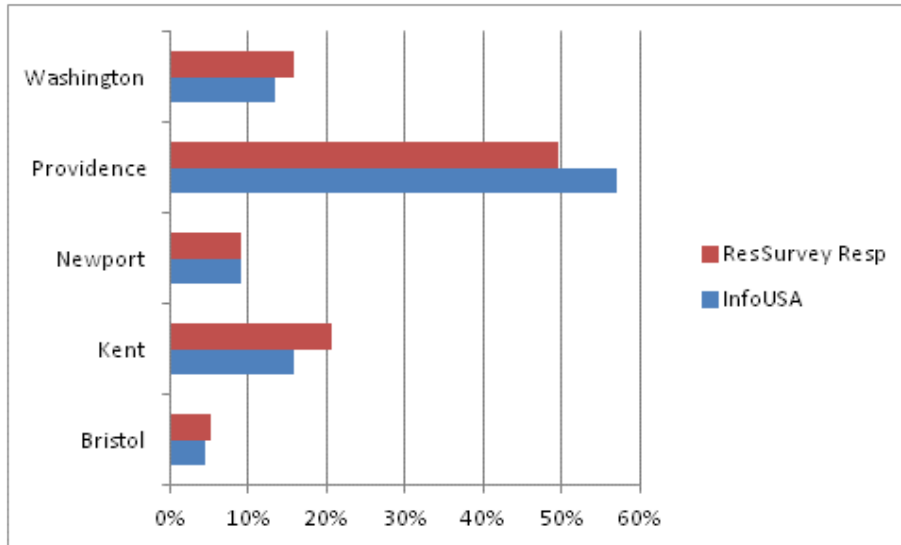
<sup>42</sup> The author of this study for Rhode Island / NRDC was an advisor / reviewer to the PSI study.

## Appendix B: Response Rate Comparisons

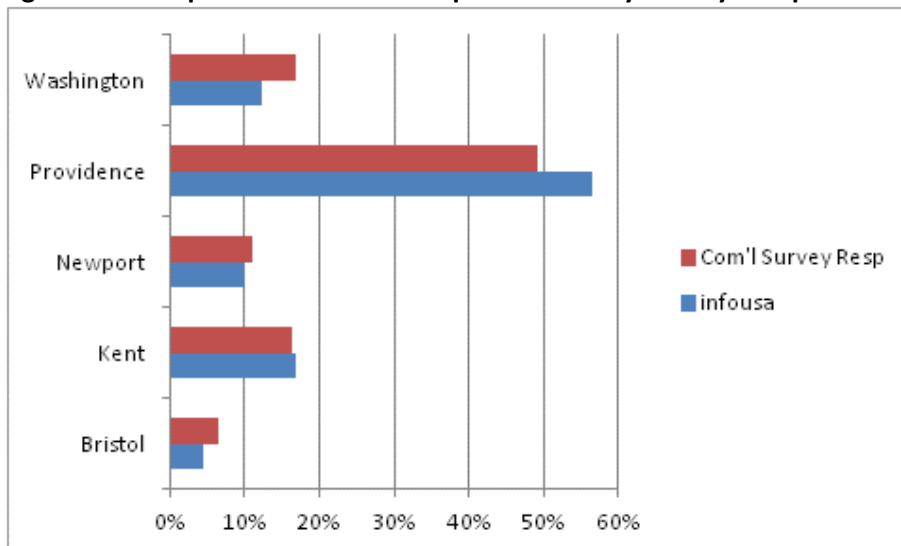
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Figures B.1 and B.2 compare the response rates for residential households and commercial businesses, by county, to the purchased population. Although there are differences, there did not seem to be significant enough in the way of systematic differences to warrant complex re-weighting by county.

**Figure B.1: Graph of Residential Response Rates by County Compared to Purchased Population**



**Figure B.2: Graph of Commercial Response Rates by County Compared to Purchased Population**





## Appendix C: Detailed Validation Results

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

Number of Thermostats identified by "type", all validations combined	COMMERCIAL		RESIDENTIAL	
	Number Therm with Mercury/ Number viewed	% WITH MERCURY from ONSITE	Number Therm with Mercury/ Number viewed	% WITH MERCURY from ONSITE
Square	9/14	64%	4/5	80%
Round	24/25	96%	1/1	100%
Digital	0/91	0%	0/1	0%
Snap	0/2	0%	0/1	0%
Lever / Dial not in photo	0/0	N/A	0	N/A
TOTAL	33/130	25%	5/8	63%

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

	Total Reported in Survey	Total Verified On-site & camera	Verified divided by Reported
Mercury Containing types	78	94	121%
Non-Mercury-containing types	152	175	115%
Total	230	269	117%

## Appendix D: Survey Instrument

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### Rhode Island Recycling/Hard-to-recycle Survey

#### A. Introduction

Please help improve recycling programs in the State of Rhode Island. Over the next year, the State is tasked with researching some specific recycling options, and we are investigating ways to improve recycling programs including programs for several hard-to-recycle items. The results of this study will be used to improve the design of recycling and disposal programs across the State. Your building/home is one of a small sample selected to “stand in” for all the buildings/homes in the State of Rhode Island, so your help on this survey is VERY important. Your response will enter you into a drawing for one of six \$100 gift certificates to Best Buy or Target, and a grand prize of a Kindle Fire HD tablet. To be eligible, you'll need to answer a couple key questions. 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 your help!

#### B. Building 1

Please think about the address that was included on the postcard that directed you to this survey, or the address of the company to which the email was directed.

1. How did you hear about this survey / what directed you to this survey? (color of postcard)

- Pink postcard (house)
- Yellow postcard (apartment/multifamily)
- Orange postcard (small business)
- Purple postcard (medium business)
- Green postcard (large business)
- Blue postcard (large business)
- Email (please answer for your BUSINESS facility)
- Other
- Not sure
- Other (please specify)

2. What is your 5-digit zip code? (not for identification, but to check representativeness of results)

3. In which county in the State is this building/home located?

4. Is this address a... (please check best answer) (type of building)

#### C. Commercial Recycling

The preferred respondent would know about the business's recycling program and about wall thermostats. For small businesses, it may be the owner, manager, or (long-term or other) employee; for larger businesses, the facilities manager, maintenance department, or others may be most suited. If these people are not available (or unlikely to answer) please answer the survey for us yourself to the best of your ability!

1. What is your job title and years at the location?

- Your job title?

- How many years have you worked at the location?

2. Do you have a recycling program at this location?

- Yes, for employees
- Yes, for customers
- Yes, for both
- No
- Don't know
- Other (please specify)

3. If yes, how does the program work? (check all that apply)

- No program
- We contract with our trash hauler to collect
- We contract with a recycling company to collect
- The city/county collects
- The property management company handles the program
- Don't know
- Other (please specify)

4. Is the program mandatory?

- Yes, I think all commercial properties in my area are required to recycle
- No
- Don't know
- If no or don't know, why does your business recycle?

5. Please select which materials are recycled/diverted at your location? (check all that apply)

- Office paper
- Magazines
- Cardboard
- Cereal box-type packaging
- Plastic containers
- Glass
- Aluminum
- Tin
- Plastic bags
- Plastic packaging
- Food waste
- Yard waste
- Electronics
- Wood waste
- Other (please specify)

6. What recycling programs, if any, would you like to see the State focus on?

#### **D. Thermostats**

We are interested in learning more about thermostat disposal and replacement in Rhode Island. Responses to the following set of questions will help the State improve possible thermostat recycling programs.

1. Approximately when was this building built? This information is very important – please make your best estimate.

2. Are there wall thermostats to control the heating and/or cooling temperatures in your building?

- Yes
- No
- Don't know

3. Number of thermostats (This question is very important; we appreciate a quick walk-around wall count)

- Approximately how many wall thermostats are located in your space in the building?
- How many are still operating?

4. To the best of your knowledge, about what year were (all or most of) the wall thermostat(s) installed in your building?

- What years were others installed? Please provide the best estimate(s) you can.

5. Do you believe the wall thermostats date from when the building was built (original equipment)?

- Yes, all of them are (or seem) original
- No, none are (or seem) original
- Not all, but more than half seem original
- Some, but fewer than half seem original
- There are no wall thermostats
- Don't know

6. About what year did your firm move into this space or building?

7. Have these wall thermostats been in place since before your firm moved in?

- No changes all
- wall thermostats here since before we moved in
- All have been replaced since we moved in
- Not all, but more than half replaced since we moved in
- Some, but fewer than half replaced since we moved in
- There are no wall thermostats
- Don't know

IMPORTANT: About how many in place since before you moved in? (please specify)

**E. Thermostat Pictures**

We are showing a few pictures of general "classes" of thermostat types below (be sure you can see the round & snap types on the right). We'll be asking about which type are in your building...

1. Which of the above picture(s) best matches the wall thermostat(s) CURRENTLY in your space in the building? Brand does NOT matter. List the approximate NUMBER of each type in your space in the building. (This question is VERY important for our study and MUST be answered to be eligible for the prize. Please make sure to provide your best estimates for all columns).

Type	Number currently in building	Number still working	Estimated year they were installed
Square type 1 or 2			
Round type			
Digital electronic type			
Snap type			
Not in photo but other digital/electronic			
Not in photo but other thermostat with lever or dial to raise/lower temperature			
Other thermostat type			

2. Looking at the same pictures, can you report how many of each type have been removed? This is also a very important question please try your best. (Again, brand does NOT matter.)

Type	Number that used to be in building but have been removed	Year they were removed (best estimate)	Approximate year they were originally installed
Square type 1 or 2			
Round type			
Digital electronic type			
Snap type			
Not in photo but other digital/electronic			
Not in photo but other thermostat with lever or dial to raise/lower temperature			
Other thermostat type			

If additional thermostats have been removed, please describe number, removal date, and age here (or if some of one type were removed at two different times)

3. Approximately how many total thermostats were replaced/removed?

### F. Thermostats 2

1. To the best of your knowledge, why were the wall thermostats removed and/or replaced? (check all that apply)

- No replacement
- Expansion of building space
- Broke/stopped functioning
- Wanted to install programmable type
- Utility replaced / utility program
- Conversion of space for new use(s)
- Renovations or replacement of heating, cooling, or electrical system
- Don't know
- Other (please specify)

2. Was the heating / cooling system replaced or updated without removing existing wall thermostats?

- No changes
- Yes, sure
- Yes, pretty sure
- No
- Don't know

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

- No replacement
- Contractor disposed – Don't know what he did with them
- Contractor disposed and said they were going to special recycling or other facility for proper disposal
- They were disposed of in the trash
- They were delivered to a recycling facility/program/hazardous material facility
- They were used in other locations in building or another building
- We still have (some or all of) the old ones in storage
- Don't know
- Other (please specify)

4. About how many removed or unused thermostats do you have awaiting discarding or recycling?

**G. Building ownership, size, activities**

Please think about the address that was included on the postcard that directed you to this survey or the business to which the email was delivered.

1. Are there multiple businesses in this building?

- Yes
- No
- Not sure
- Other, specify

2. About how many businesses are in this building?

- One Only -our firm
- 2
- 3-5
- 6-10
- More than 10
- Other (please specify)

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

- <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)

4. Do you own or rent the space you occupy?

- Own or buying
- Long term lease (more than 3 years)
- Short term lease / rent (3 or fewer years)
- Other (please specify)

5. Which category best describes...

	Your business – locally within this building	Your business – at head-quarters located elsewhere	Federal, state, county, or city government	A property management company
...the organization that manages the building?				
...who makes decisions about building equipment, heating systems, thermostats, etc.?				

6. What is your best estimate of the size range for YOUR SPACE and for this BUILDING? (separate columns)

- 1,000 sq ft or less
- 1001-5,000 sq ft
- 5,001-10,000
- 10,001- 20,000
- 20,001-50,000
- 50,001-100,000
- 100,000- 300,000
- 300,001 sq ft or more
- Unsure

7. What is the best range for the number of employees in this building for YOUR FIRM and the WHOLE BUILDING (including yourself)? (separate columns)

- 1-2
- 3-5
- 6-9
- 10-19
- 20-49
- 50-99
- 100-249
- 250-499
- 500 or more Unsure

## H. Heating Systems & Computers

1. Does this building have central heating and/or central air conditioning? (check all that apply)

- Yes, central heating system with thermostat(s)
- Yes, central cooling system with thermostat(s)
- No central heating or cooling system controlled by thermostat(s)
- Not sure
- Other (please specify)

2. We have a couple of questions about electronics / computers and their disposal / recycling...

- About how many computers are in use in your firm?
- About how many computers are broken / stored?

3. What is your computer replacement policy? (check all that apply)

- Replace only when they are broken
- Replace many / most / all at one time (specify how long between replacements)
- Dispose of the computers in trash
- Recycle the computers at a facility
- Recycle the computers through a firm
- Donate the computers
- Reuse computers elsewhere
- Other (specify)
- Computer replacement cycle in months or years; Other (please specify)

## I. Commercial Ending

1. If you are satisfied with your answers, please click on the "Done" button below.

## J. Residential Recycling

1. Do you have recycling collection at your house/apartment?

- Yes-it is included in our trash bill
- Yes-we signup and pay extra for recycling
- No-we do not have recycling
- Other (please specify)

2. Who collects your recycling?

- Our trash hauler
- A recycling company
- The city/county collects the recycling
- Not sure
- Other (please specify)

3. How is recycling collected? (check all that apply)

- We do not have recycling collection
- We take recyclables to a dropoff location
- We put all our materials in one container collected at our house
- We separate into two containers (one for paper, one for containers)
- We separate into more than two containers
- Don't know
- Other?

4. If you have recycling collection, how often is it collected?

- Twice a week
- Weekly
- Every other week
- Once a month
- No collection
- Don't know
- Other (please specify)

5. If you have a recycling program, why do you/your family choose to recycle? (please select all that apply)

- It is mandatory
- We pay for it so we might as well recycle
- It helps save money on our trash bill
- My kids want to
- All of my neighbors are doing it
- It saves natural resources
- It saves space in the landfill
- It can reduce greenhouse gases
- It is easy and convenient
- It is good for our economy
- We do not recycle
- Other (please specify)

6. Do you have organics/yard waste collection?

- Yes, we have yard waste collection year round
- Yes, we have yard waste and food waste collection year round
- Yes, we have yard waste and food waste collection seasonally
- Yes, we have yard waste collection seasonally
- Yes, we have yard waste collection seasonally
- Yes, we have food waste collected year round
- No
- If yes, does it cost extra to have this service?
- Other-please specify

7. What changes, if any, would you like to see the State undertake to improve recycling?

### K. Residential Thermostats

Rhode Island is very interested in learning about disposal and replacement of wall thermostats. Responses to the following set of questions will help the State better plan potential thermostat recycling programs.

1. Approximately when was this home/building built? This information is very important – please make your best estimate.

2. Are there wall thermostats to control the heating and/or cooling temperatures inside your residence?

- Yes
- No
- Don't know
- Other (please specify)



3. If you live in an apartment- Are there wall thermostats to control the heating and/or cooling temperatures in “common spaces” (entryway for apartment building, etc.)

- Yes
- No
- Don't know
- Other (please specify)

4. Number of thermostats-This question is important. Please take a quick walk around to see...

- Approximately how many wall thermostats are located in your home/residence?
- How many are still operating?

5. To the best of your knowledge, what year were the wall thermostat(s) installed in your home?

- If multiple years, put additional years here. Please provide the best estimates you can.

6. Do you believe the wall thermostats date from when the home was built (original equipment)?

- Yes all are (or seem) original
- Some are (or seem) original
- None are (or seem) original
- Don't know
- Other (please specify)

7. Approximately when did your family move into this home?

8. Have these wall thermostats been in place since before your family moved in?

- Yes all of them
- Some of them
- None of them all replaced
- Don't know
- Other (please specify)

**L. Residential Thermostat Pictures**

We will be asking questions about the following thermostat "types" (be sure to notice the round and snap types on the right)...

1. Which of the above picture(s) best matches the wall thermostat(s) CURRENTLY in your space in the building? Brand does NOT matter. List the approximate NUMBER of each type in your space in the building. (This question is VERY important for our study. Please make sure to provide your best estimates for the columns)

Type	Number currently in home (or unit)	Number still working	Estimated year they were installed
Square type 1 or 2			
Round type			
Digital electronic type			
Snap type			
Not in photo but other digital/electronic			
Not in photo but other thermostat with lever			

Type	Number currently in home (or unit)	Number still working	Estimated year they were installed
or dial to raise/lower temperature			
Other thermostat type			

2. Looking at the same pictures, can you report how many of each type have been removed? This is also a very important question please try your best. (Again, brand does NOT matter.)

Type	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
Square type 1 or 2			
Round type			
Digital electronic type			
Snap type			
Not in photo but other digital/electronic			
Not in photo but other thermostat with lever or dial to raise/lower temperature			
Other thermostat type			

If additional thermostats have been removed, please describe number, removal date, and age here (or if some of one type were removed at two different times)

### M. Residential Thermostats 2

1. Approximately how many TOTAL thermostats were replaced/removed?

- Clarify larger counts; Other issues (please specify)

### N. Residential Thermostats

1. To the best of your knowledge, why were the wall thermostats removed and/or replaced? (check all that apply)

- No replacement
- Expansion of the home
- Renovations or replacement of heating, cooling, or electrical system
- Thermostats not working/stopped functioning
- Wanted to install a programmable type
- A utility company program
- Don't know
- Other (please specify)

2. Was the heating / cooling system replaced without removing existing wall thermostats?

- No changes to heating/cooling system
- Heating/cooling system changed without removing wall thermostats
- Heating/cooling system changed WITH change /replacement of thermostats
- No thermostats
- Don't know
- Other (please specify)

3. Who made the decision to remove / replace the wall thermostats and/or heating system?

- No replacement
- My family
- Landlord
- Home owner association
- Property manager
- Other (please specify)

4. Do you know what happened to the removed wall thermostats? (check all that apply)

- No replacement
- Contractor disposed – Don't know what he did with them
- Contractor disposed and said they were going to special recycling or other facility for proper disposal
- They were disposed of in the trash
- They were delivered to a recycling facility/program/hazardous material facility
- We still have (some or all of) the old ones in storage
- They were used in other locations in home / another home
- Don't know
- Other (please specify)

5. About how many removed or unused thermostats do you have awaiting discarding or recycling?

6. Does your home have central heating or central air conditioning? (check all that apply)

### **O. About the Home**

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

1. If you are in a multifamily building: Approximately how many apartment units are in this building?

- Yes, central heating and air conditioning controlled jointly by a thermostat
- Yes, central air conditioning with a thermostat (separate from window units)
- Yes, central heating system with a thermostat (separate from baseboard heaters)
- No, we have neither
- Not sure
- If other, please specify

2. Do you own or rent your home/apartment?

- Own or buying
- Rent / lease
- Other (please specify)

3. About how large, in square feet, is your residence?(Please DO NOT include garage or unheated spaces like crawl spaces)

4. How many...

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

5. Including yourself, how many persons normally live in this residence on a fulltime basis?

6. What is the highest grade of schooling completed by the head of household?

- Grade school
- Some high school
- High school graduate
- Some college
- Business / technical school
- College graduate
- Some graduate school
- Graduate degree
- Other (please specify)

**P. Thanks!**

Thanks you very much for taking the time to complete our survey. Both your time and input are invaluable to us.

1. Are you planning any remodels or changes that will remove thermostats?

- No
- Yes, in 2013
- Yes, in 2014-2015
- Yes, other year
- Not sure

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

- Yes
- No
- Not sure

3. What do you typically do with your home's old compact fluorescent light bulbs (CFLs)?

- We don't use CFLs, we use traditional bulbs
- We don't use CFLs, we use newer bulb types (LEDs)
- Throw directly in the trash
- Put in a bag or other container and put in the trash
- Bring to a recycling facility to dispose
- Bring to a landfill / transfer station to dispose
- Bring to a retailer to dispose
- Not sure
- Other (please specify)

4. How do you normally dispose of your household alkaline batteries (AA, AAA, etc. type batteries)?

- Throw in trash
- Put in recycling bin
- Bring to hazardous waste center
- Bring to recycling center
- Not sure
- Other (please specify)

1. PRIZE: Would you like to be entered into the drawing for one of six \$100 gift certificates or a Kindle Fire HD 7" tablet?

- Yes
- No
- IF YES, please provide your name, phone number, business address / address, and email.

1. Please enter your contact information to be eligible for the prize.

2. If you would like to receive a summary of the results of this survey, please provide an email address below.

- Name:
- Business / Home Address:
- City
- Phone:
- Email:

3. If you are willing to provide your address, we can link to a database that gives a good estimate of the date your building / home was built. If you were uncertain about construction date in our questions, this address information would be very helpful. It will not be used to identify you. Please enter address / city / zip if you are willing or if you were uncertain of this date.

Please click next.

1. Would you be willing to be contacted with any follow up questions about your thermostats?

- No, please do not contact me
- Yes, you may contact me
- If yes, please provide a way to contact you.

**Q. Thanks!**

1. If you have any other comments or questions about the survey or project please let us know:  
THANK YOU for completing our survey!