Memorandum

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From: Bretnie Eschenbach and the Commercial HVAC Team, Cadeo

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Subject: TO32 Commercial HVAC Data Collection Lessons Learned

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Introduction

The Cadeo and SBW team (the research team) developed a set of commercial HVAC data using public permits ("permit database") on behalf of Bonneville Power Administration (BPA) using data gathered from public records on commercial new construction and major renovation building projects completed during the Northwest Power and Conservation Council's (the Council) Seventh Power Plan (Seventh Plan) Action Plan Period (2016-2021). This data will inform commercial HVAC electricity consumption estimates in a planned 2022 commercial HVAC market model. Table 1 summarizes the commercial HVAC data collection scope.

Table 1: Commercial HVAC Data Collection Scope

Parameter	Requirement
Building Types	Commercial buildings Multifamily buildings with five or more units and four or more floors, if central system
Analysis Period	Operational between January 1, 2016 and December 31, 2021
Geography	Installed in Idaho, Oregon, Washington, or Montana counties served by BPA

This memo has two primary objectives:

1. Describe the methodology the research team followed to collect and catalog commercial HVAC permit data
2. Summarize the key lessons learned and recommendations for future data collection

Methodology

This section describes at a high level the methodology used to collect and catalog commercial HVAC permit data. The research team performed six commercial HVAC data collection:

1. Develop a sampling plan
2. Develop a sample project frame to represent the population of projects within the study scope
3. Draw a representative sample of projects from the frame
4. Gather permit data and supporting documentation for selected projects through public records requests and secondary sources
5. Use those data to characterize the prevalence and characteristics of HVAC systems appearing in the sample
6. Extrapolate the prevalence of HVAC systems and their characteristics to the entire BPA region as a regional data resource and for use in the eventual market model

BPA will use the extrapolated database to estimate total new construction commercial floor area served by new HVAC systems and the share of that floor area associated with various types of HVAC systems. This memo focuses on Steps 4 and 5, while the February 2021 Sampling Plan Memo (TO32 Task 2c) and Sample Frame Spreadsheet (TO32 Task 3b) describe in detail Steps 1 – 3 and 6.

The research team used the following methodology to acquire project plan sets from permitting jurisdictions and catalog the data in those permits:

1. For each sampled project, the team requested permit files from permitting jurisdictions through each jurisdiction's public records request process, typically an online request form. Most jurisdictions required additional information, and some (an estimated 25%) required permission from the owner or charged fees for providing plan sets. When jurisdictions were not able to provide plan sets within the research team's timeframe, researchers requested files directly from the owner or architect, or used an online permit aggregator, ConstructConnect, as secondary resources.[1]
2. If a project fell outside of BPA's scope or files were unavailable through the jurisdiction or ConstructConnect, research the team replaced the project following the sampling plan's replacement process.
3. Once the research team acquired a project's plans, researchers cataloged the data associated with each project in two stages.
    a. Stage 1 cataloging captured basic project information including project square footage, completion date, and primary heating and cooling systems. If Stage 1 cataloging identified a project's primary heating or cooling system as a Variable Refrigerant Flow

[1] The team purchased an account to access ConstructConnect's online permit database, https://www.constructconnect.com/. Contractors typically use ConstructConnect as a lead-sourcing website for construction activity; however, ConstructConnect also includes digital records of building permits and approved plan sets for some permitted projects.

(VRF), Ductless Heat Pump (DHP), Air Source Heat Pump (ASHP), or ducted cooling system, the research team cataloged additional HVAC system information in Stage 2. [2]

b. Stage 2 cataloguing captured detailed system variables including capacity, efficiency, heat recovery ventilation (HRV), fan horsepower, and supplemental HVAC systems.

4. The team performed quality assurance (QA) review on each project to ensure information accuracy. Every project received at least one round of QA review in Stage 1 to confirm the data entry matched the plan sets. In Stage 2, projects received two rounds of additional QA review by HVAC technical leads. Any project in which cataloging staff noted uncertainty received additional review by technical leads.

The research team extrapolated the completed sample to the full population and calculated the relative precision around the population estimate using the linear regression estimate approach described in *Sampling Techniques* (Cochran 1977, Ch 7). The analysis uses square footage, construction value, and the number of projects in the sample and full population by domain. The domains are stratified by building type, geographic location (east or west of the Cascades), and project size. The size strata were uniquely determined within each domain based on distribution of construction values. The team extrapolated the sample to the full population by multiplying each project's square footage by the expansion weight, which is the population of the stratum divided by the number of completions in the stratum.

The research team implemented three population estimation techniques and determined the regression approach resulted in the best relative precision for almost all domains. The regression estimate fell within the error bounds of the two other techniques for the remaining domains, further boosting confidence in this approach. The full data set includes additional detail on the three techniques considered, the extrapolation process, and the relative precision of each domain.

Lessons Learned

The research team encountered data collection successes and challenges that can inform how BPA implements future data collection efforts. This section describes the lessons learned and recommendations for BPA based on those experiences. The lessons learned fall into three activity categories:

1) Acquiring files from jurisdictions and secondary sources
2) Cataloging HVAC systems
3) Sampling plan implementation and final sample analysis.

Acquiring Files from Jurisdictions and Secondary Sources

The research team requested project plan sets through jurisdictions' formal public records request processes, defined by each jurisdiction. The team developed this approach based on previous pilot project

[2] BPA defined these HVAC systems as key technologies of interest, or "principal technologies" during project planning. "Ducted cooling systems" include unitary air conditioning systems such as cooling-only heat pumps and packaged rooftop units with electric cooling.

permit-gathering experiences comparing permitted vs. installed conditions. Acquiring permits for this full-scale data collection effort proved more challenging than the pilot project, but also resulted in many successes, described in more detail in Table 2. The research team's recommendations for future data collection follow Table 2.

Table 2: File Acquisition Challenges and Mitigation Strategies

Challenges	Mitigation Strategies
Pandemic restrictions associated with COVID-19 caused delays in acquiring plan documents. Limited staff availability in-person access restrictions reduced options to review and scan physical files and increased pressure on jurisdictions' staff. These challenges resulted in long wait times for some jurisdictions, and other jurisdictions were unable to provide any files.	Taking a flexible and communicative approach to what is typically a formal process allowed the team to successfully work through unexpected pandemic challenges. Researchers adjusted by working with staff at jurisdictions to find agreeable solutions. Some jurisdictions preferred sending all relevant files for the research team to review, while others preferred researchers make the request as specific as possible to help them identify the right files. Some jurisdictions worked with the research team on creative solutions, such as taking photos of files when they would normally allow users to copy physical files or working through options over the phone.
Unexpected bureaucratic barriers such as unreasonably high costs for public records requests, months-long timeframes to send files, or responses claiming exemption from public records requests led to higher replacement rates and longer timeframes.	The research team used two secondary sources before replacing a project when the public records request process faced challenges or delays: 1. Requested files directly from owners or architects (3% of the final sample's files) 2. Used ConstructConnect. The research team added this option midway through the data collection process and found the ConstructConnect account a viable option for 15% of projects.
Unclear jurisdictional ownership where multiple agencies (e.g., city, county, state) could be responsible for maintaining project records required additional records request communication. This included contacting multiple agencies to identify the correct owner of the files and/or multiple rounds of communication with jurisdictions to obtain the complete and correct plan set.	Using different forms of communication kept processes moving when jurisdictions required multiple rounds of follow-up to receive files. While email provides documentation and allows for copying multiple individuals, telephone communication reduced time associated with back-and-forth clarifications.

Challenges	Mitigation Strategies
Smaller jurisdictions had fewer staff resources or did not handle public records requests often and thus did not always have files on record or needed very long timeframes to provide files.	The same flexible approaches used to minimize pandemic challenges also helped create solutions with smaller jurisdictions (e.g., working directly with the jurisdiction staff to identify the best path forward).
Larger jurisdictions that had many projects in the sample needed long timeframes to provide all requested files. One city stopped fulfilling the research team's records requests after receiving what they determined to be too many requests (40) given their staffing and remote-work challenges.	When the city stopped fulfilling the research team's records requests, a BPA Energy Efficiency Representative helped researchers by identifying a utility staff resource who could help download the requested files, thus minimizing impacts on the records office. While this was the only city with a request this large, this strategy could be helpful in working with jurisdictions with more than 10 requests.
Late project sample replacements extended the collection timeframe, increasing the risk that those projects would also need replacement.	As the project timeline neared the end, the research team requested more than the needed files and used the first project file the jurisdiction sent. While this tactic would be time-consuming to implement on the entire sample, it proved useful for receiving files faster than single requests at a time.

Future Data Collection Recommendations

1. **Use online secondary data sources to supplement public records requests.** Leveraging online sources such as ConstructConnect will be increasingly useful as more jurisdictions move to digital file storage. This recommendation would simplify document acquisition and reduce the burden on jurisdiction staff to physically scan or copy files.

   The research team did not acquire a ConstructConnect account until late in the data collection project but recommends integrating these data at the beginning of any future data collection. The online permit aggregator only had files for 10% of projects in the sample, but this percentage should increase over time as more jurisdictions move to digital files, and ConstructConnect increases its coverage. The research team recommends using ConstructConnect (or a similar aggregator service) first to find the sample's permit files, and then sending public records requests only if ConstructConnect does not include the project files. This process could save 10-25% of data collection time, depending on how much ConstructConnect's digital file availability increases and what percentage of the future sample can be obtained through their system.

2. **Work with large jurisdictions in advance of future data collection efforts.** The region's largest jurisdictions unsurprisingly had a high number of projects in the sample, which required substantial interactions with the jurisdictions' public records staff. The following jurisdictions included more than 10 projects in the sample: Seattle, Portland, Boise, Meridian, and Bellevue. In

future data collection efforts, the research team recommends BPA contact jurisdictions through existing energy efficiency partnerships in advance to explain the research, confirm the jurisdiction has resources to support the work and identify an approach that works for both parties (e.g., agreeing on timeframes, batched requests and communication preferences, and strategies to minimize the burden on jurisdictions).

3. **Request more projects than the sample requires to minimize replacement delays.** The research team started by requesting project files for the 300 sampled projects, only adding cases when it became apparent a replacement project was required. This approach reduced the time required to request files but created delays when projects dropped out. To keep the project on schedule, the research team requested more projects than needed to complete the sample within the established timeframe. Ultimately, the research team requested records of 520 files to complete the sample.

   The research team recommends a two-phased approach for future data collection efforts. For the first phase, researchers recommend requesting only original sample records (looking in secondary data sources first, as described in number one above). After identifying initial replacement for specific strata and domains, the research team recommends a second phase of requests including replacements plus 25-50% additional backup replacement records. The number of additional requests would depend on the number of projects in each strata and domain and the number obtained in the first phase. For example, if one domain of the sample includes 10 projects out of a total 100 projects in the population, and the team receives seven of the 10 requests in the first phase, the team may request six replacement projects to fulfil the remaining three projects in the sample, but will use judgment to balance the burden of requests on jurisdictions and the timeframe available to make additional requests. The exception to this recommendation is projects in the largest two strata, which have fewer replacement options and a higher likelihood to need replacing, as jurisdictions had more difficulty providing files for the largest projects in the sample.

   The research team also recommends establishing a firm project replacement timeline. If project files are not received within a specific number of weeks, the project will require replacement. During this data collection effort, the research team worked with jurisdictions until it was clear they would be unable to provide the files. Researchers prioritized obtaining projects in the original sample over the time it took to receive those projects, but this approach resulted in long timeframes and late replacements. The research team recommends setting a firm deadline for obtaining files and replacing projects more quickly when jurisdictions are unable to provide files within that timeframe.

4. **Take an "account management" approach to working with jurisdictions.** The research team found each jurisdiction had unique processes and constraints, with no single solution or approach that worked for everyone. Researchers recommend approaching future jurisdiction data collection with flexibility, such as adapting to their staffing and administrative situations, identifying barriers early, building positive relationships with staff, and being open to creative solutions. Examples include providing options for identifying the correct plan set, specifying ways to narrow the request, providing project files specifics, offering to receive the mechanical plan set vs. the full plan set, and reaching out via phone to resolve issues.

Cataloging HVAC Systems

The permit cataloging team (catalog team) included a team of Cadeo analysts supported by technical advisors. The advisors are experienced mechanical engineers with technical expertise in commercial HVAC equipment. Advisors trained catalogers on using the data entry tool and commercial HVAC system basics and provided technical support to reduce the number of judgment calls catalogers needed to make. Table 3 summarizes the catalog team's challenges and successes, followed by recommendations for future data collection.

Table 3: Cataloging Challenges and Mitigation Strategies

Challenges	Mitigation Strategies
Cataloging permit data requires significant time and oversight to ensure entries are accurate and complete, particularly with the complexities of commercial HVAC equipment, which can include different names for the same equipment, unique applications, and large plan sets. Using analysts for review and data entry lowers costs, but still requires experienced senior technical staff for quality control, guidance, and process planning.	The catalog team was comprised of detail-oriented people who performed critical review and asked detailed questions to ensure the database is accurate and free from mistakes. While catalogers were not all engineers, the training and QA process worked well to catch mistakes.
Technical data collection projects require critical review and detailed QA to ensure entries are accurate. The research team structured the project with a consistent QA process that would reduce errors, but complex projects with large plan sets required more time than originally anticipated.	The data entry tool created as part of TO32's Task 3a provided a reliable method for the catalog team to catalog permit data. The tool's embedded flags and checks enabled catalogers to catch mistakes as they cataloged, and the tool's outputs allowed technical reviewers to QA throughout the project. The tool included flags when an entry resulted in values outside typical entry bounds and validation lists provided users with guided options.

Future Data Collection Recommendations

1. **Create strong data entry protocols and documentation processes to ensure the final product is accurate.** Future data collection effort could continue to rely on junior staff for cataloging but should also include members with technical and data collection experience. A ratio of four junior staff per technical subject matter experts served this project well, but could vary depending on the expertise of the junior staff. The catalog team should create well-documented processes and resources to eliminate judgement calls, and update those documents as the project progresses with common questions and corrections found during the QA process.
2. **Continue to build on existing technical resources to support non-technical team members.** Future data collection should leverage BPA's existing tools and resources (developed through this

project or past projects) to assist future catalogers with HVAC system information. Tools and resources include training staff on commercial HVAC equipment and reading construction documents, maintaining an FAQ document, and providing real-time access to mechanical engineers for questions and QA.

Sampling Plan Implementation and Final Sample Analysis

The research team successfully implemented the sampling plan by obtaining and cataloging permit data from 365 projects. Researchers requested records for 520 projects, resulting in a sample of 299 projects with HVAC data, and 66 projects without new HVAC system data. The research team analyzed the final sample to understand replacement trends and inform future data collection efforts. Table 4 summarizes the research team's challenges and mitigation strategies in sample plan implementation, followed by recommendations for future data collection.

Table 4: Sample Challenges and Mitigation Strategies

Challenges	Mitigation Strategies
The research team had a higher rate of replacement (needed to request more projects to complete the sample) than occurred in BPA's pilot project. The pilot project did not include a random sample nor targeted jurisdictions with easier records request processes (online systems). Researchers expected a higher replacement rate, but this resulted in longer data collection periods than anticipated. Table 5 discusses replacement project reasoning.	Of the 520 projects requested, the research team cataloged 299 of the targeted 300 projects with new HVAC systems, and obtained an additional 66 projects that did not include new HVAC systems or were not yet complete. Future data collection efforts should account for an attrition rate of 42% to achieve future samples. [3]
Of the 520 projects requested, 66 projects were out of scope. These projects were either unconditioned buildings, projects without *new* HVAC systems (existing systems remained unchanged), or projects not yet completed.	The sample frame would ideally exclude these projects, so the research team factored the rate of out-of-scope projects into the extrapolation of the final data set.

[3] The team did not fully meet the target sample of 300 due to finding a misidentified project in the final database review process.

Challenges	Mitigation Strategies
The sample frame developed from Dodge Data and Analytics[4] (Dodge) data has gaps and limitations that required adjustments when the research team implemented the sampling plan. These gaps include projects without enough identifiable project information to match it to a jurisdiction's permitted project (e.g., no address, vague location, or no project description or name), misidentified building types, or gaps in square footage data.	The Dodge data set, while imperfect, still provided robust data information the research team successfully used to match and request permits from jurisdictions. The research team considered approaches to resampling based on sub-building types, but found this would compromise the original sample and make the final sample impossible to use.
The sample plan relied on Dodge's Construction Value estimate as a proxy for square footage due to Dodge's incomplete square footage data. Final analysis of the cataloged square footage data indicates Construction Value is a poor proxy for square footage and contributed to poor relative precision in some domains. Six of the 22 domains had a relative precision of 20% or higher, meaning a higher degree of uncertainty when extrapolating project representativeness in those domains.	Despite the poor correlation between Construction Value and square footage in some domains, the final sample achieved good relative precision, with 13 of 22 domains having a relative precision of 10% or lower, and an overall average relative precision of 12%. The recommendations below expand on the use of Construction Value in future data collection.
Half of the certainty strata, the sample's largest project strata, had no or one completion (11 of 22). This means these large projects did not contribute to the population estimation. Additionally, one domain's lower stratum, east restaurants, had no completions, missing a target quota of three projects, which means those projects did not contribute to the population estimation for that domain. For the missing certainty strata, this could mean the final extrapolated population underestimates floor area of those domains. For the missing lower stratum cases, the extrapolated population overestimates that domain.	Since the sample design based the original strata on Construction Value, and collected data revealed poor correlation between the Construction Value and conditioned square footage, post-stratification based on collected square footage would be required to determine how the missing cases actually impacted population estimates.

Table 5 provides project attrition and replacement reasoning.

[4] The team purchased data from Dodge Data and Analytics, an aggregator of construction project data, primarily targeting manufacturers, contractors, and project developers in search of bidding opportunities. Multiple vendors aggregate tax assessor parcel and permit data from counties and smaller jurisdictions, with varying coverage and quality of information, but the team determined this data set to be the most robust for sampling purposes. For more detail on Dodge, see the February 2021 Sampling Plan Memo (TO32 Task 2c) and Sample Frame Spreadsheet (TO32 Task 3b).

Table 5: Project Replacement Reasoning

Percent of Replacements	Reason for Replacement
89%	Jurisdiction unable to provide files (including not having files on record, unwilling to provide files for proprietary or confidentiality reasons, or unable to send files within a reasonable timeframe or cost)
11%	No address match (i.e., the sample frame's data set did not include enough specificity to successfully match the address or building description to a building and permit)

Future Data Collection Recommendations

Two primary challenges inform the team's recommendations for future data collection.

First, in the process of requesting and receiving files, the research team found 66 out-of-scope projects that needed replacement (e.g., projects that do not include new HVAC systems or were not yet complete). While researchers replaced these projects, the full sample also includes potential out-of-scope projects that factor into the extrapolation. The team does not know of alternative strategies that would exclude out-of-scope projects from the original sample frame, but the recommendations below seek to mitigate the challenges out-of-scope projects presented.

Second, Dodge's incomplete square footage data presented a challenge in developing the sampling plan. The sampling plan used Dodge's Construction Value as a proxy for square footage to stratify the sample with the intention to extrapolate results based on the final cataloged conditioned square footages. However, analysis of the final sample with complete square footages indicates Construction Value does not correlate well with square footage, which affected the relative precision of some domains. Six of the 22 domains had relative precision of greater than 20%, in part due to this issue, which increases the uncertainty of extrapolated population estimates in those domains. The first two recommendations below seek to eliminate the need for using construction value as a proxy for square footage.

The original sampling plan considered alternatives that would exclude out of scope projects and provide a more complete square footage population, but the data collection scope did not allow for alternative sampling approaches. However, after this data collection effort, the research team recommends future data collection consider alternative sampling approaches. The research team identified three potential options to consider in the future.

1. **A two-stage sampling design** would require a large sample in the first stage, but a smaller targeted sample in the second stage. This design would mitigate both out-of-scope and sparsely populated square footages. The first stage would require collection of a larger number of permits to establish the population and sample frame. The data collected in the first stage would allow the second stage to include a more representative sample. The second sample would exclude out of scope projects. A two-stage approach would be more expensive to implement than the team's one-stage approach, so the team recommends further discussion on scope and process before implementing. For example, if BPA narrows future data collection efforts to smaller analysis

periods, fewer building types, or removes remodels from the scope, a two-stage sample design could be more feasible than the current data collection effort, which included a wide scope.

A two-stage sampling plan could also mitigate needing to use Construction Value as a proxy, by first estimating the full population, and then drawing a sample from that population, but this would require a larger scale effort to fill Dodge's square footage gaps (roughly 50% of Dodge's data excludes square footage data). The research team recommends further exploration of a two-stage approach that balances the time required to complete the square footage entries and request and catalog permits with the number of permits needed to estimate the population.

The team proposes using a combination of data sources to fill Dodge's square footage gaps including but not limited to supplemental permit aggregators like ConstructConnect, online searches for building information, and public parcel data. Collecting square footage for half of the Dodge entries could potentially be very time consuming, so the team would revisit available data in the future to identify any new sources, re-evaluate any improvements to the Dodge data, and consider limiting the scope to narrow the sample frame.

2. **A simple random sample** would remove project size (construction value or square footage) as a stratification factor, eliminating the construction value challenge, but not fully address the out-of-scope concerns. A simple random sample would require significantly more projects than other approaches, roughly four times larger, or 1,200 projects, but could result in a more robust data set given the poor correlation between Construction Value and square footage. This could simplify the data collection process by requesting a large number of projects from jurisdictions, and filling the sample with the first projects received, rather than needing to receive specific projects in the sample. This approach, however, puts additional burden on jurisdictions to provide files for significantly more projects. The team would only recommend this option if permit aggregators like ConstructConnect drastically expand their market coverage and available files or jurisdictions increase online availability of permit files through public portals.
3. **An oversample approach** would follow the current data collection effort's sampling approach, but would intentionally oversample the initial requests, knowing a percent of projects received will be out of scope. This approach would require requesting 25-45% more projects, based on the current data collection's replacement rate, but given the number of projects the research team ultimately needed to request to achieve the sample, would not increase the level of effort compared with the other two options and would represent the lowest cost option. This approach would reduce the out-of-scope challenge but would still rely on construction value as a proxy for square footage.

Of the three options presented the team recommends the first option, the two-stage sampling design, if the next data collection effort includes a smaller analysis period, fewer building types, or removes remodels from the scope. If BPA pursues a similar scope in the future, the team recommends the third option, an oversampling approach. In addition, as online data sources expand, the feasibility of each of these options may change, so the team recommends re-evaluating each option in the future before finalizing the next data collection approach.

Additional Recommendations

1. **Adjust for large project timelines.** The research team found the sample's largest projects (greater than $10 million in construction costs) were the least likely to be complete within the analysis period, reflecting the longer construction process for larger projects. When creating future sample frames from Dodge data, researchers recommend estimating a 2-year minimum lag time between project starts and completions with projects greater than $10 million construction value.
2. **Narrow the scope to new construction only.** BPA could consider excluding remodels from future data collection if future project goals do not specifically require remodel trends. Remodels represented 63% of the out-of-scope projects, so focusing solely on new construction projects in the future may reduce the number of replacements due to no new HVAC as part of the project.

This commercial HVAC data collection effort used publicly available permits to better understand the commercial HVAC market and inform a future BPA market model. Using permit data in this way provides the region with a new resource and an opportunity to gather additional data in the future. While pioneering a novel data collection method brought significant challenges, the team believes that permit records can continue be a good source of information for the region in the future and looks forward to building on the lessons learned in this project.