Title

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Screening Method to Identify High VAV Minimum Airflow Rates and Retrofit Opportunities

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ABSTRACT

Excessively high minimum airflow setpoints for Variable Air Volume (VAV) boxes, caused by outdated energy codes stipulating they should be 30% or higher of the maximum airflow, led to significant energy waste. Lower setpoints meet the ventilation code requirements while minimizing recirculation and reheat energy waste. ASHRAE RP-1515 showcased this by correcting VAV minimums in 1,000,000 ft^2 (92903 m^2) of California office space which yielded 10-30% HVAC energy savings and improved thermal comfort. Consequently, the Title 24 Energy Standards and ASHRAE 90.1 were updated to mandate minimum airflows match ventilation requirements. Beyond increased reheat energy waste caused by elevated VAV minimums, boiler operation issues can also contribute to avoidable energy waste. Despite energy codes mandating low VAV minimums for several years, these issues remain common in new construction and existing buildings. Our goal is to simplify retrofit decision-making for owners and operators by developing a screening method to assess extensive or small-scale building portfolios, using easily accessible data encompassing building type, age, size, and monthly gas consumption. The method entails applying a series of filters to a list of potential buildings to identify those with heating system challenges that should be prioritized for system upgrades. The main filter highlights buildings with elevated summertime gas consumption, as well-functioning systems lacking a major gas end-user should exhibit minimal gas usage during the cooling season. This filter employs a threshold for summer gas consumption we calculated based on standard design parameters, assumptions, and past case studies to serve as a benchmark and pinpoint problematic buildings. We applied this filter, among others, to over a decade of gas consumption data for 22 buildings at California State Polytechnic University, Humboldt. Collaborating with operators enabled us to identify 2 high priority buildings from the data set and validate the filtering process by cross-referencing floor plans and schedules to verify that these issues do in fact exist. Additionally, we applied this methodology to monthly gas data for 3318 buildings in Washington, DC to gauge its applicability on a larger scale. This process prioritized 30 potential buildings that could significantly reduce fossil fuel consumption, elevate thermal comfort, and realize gas bill savings through economical retrofits. While the screening method does not identify all buildings needing heating system upgrades, the results demonstrate how effective they are at highlighting buildings which should be prioritized to see the largest savings from the lowest cost interventions.

1 INTRODUCTION

Modern technologies have made building data recording and analysis easier and more accessible. However, although the capabilities exist, this data is often underutilized, especially for existing buildings. By using building operational data to view trends about system performance, there are several low-cost improvements that can be made to increase energy efficiency and improve thermal comfort. Even for buildings without modern energy or water

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metering technologies, there is much information to be gained by using the data from monthly gas bills if the building uses a gas-fired heating plant. Inefficient boiler operation or excessive reheat can drive up gas consumption, result in excess pollution from fossil fuel combustion, and add to thermal comfort issues. Many issues can be easily fixed by a simple controls retrofit, but building owners and operators have to be aware of both the problem and the solution.

One of the most prevalent causes of unnecessarily high gas consumption in large commercial buildings is excessive air reheating in Variable Air Volume (VAV) Systems. This is because VAV reheat systems are often programmed with outdated control logic, called single maximum logic, and minimum flowrates that are 30% of the cooling maximum airflow, or higher, as stipulated by previous energy codes. This rule was established because it was previously thought that the velocity pressure sensor in VAV boxes would lack accuracy at these lower airflows, however it has been proven that VAV boxes can modulate to much lower airflows without issue (Arens et al. 2012), (Dickerhoff and Stein 2007). The high minimum airflows prescribed by the outdated strategy result in excessive energy wasted from the reheating of larger air volumes. Thermal comfort issues also arise from over-cooling spaces in the warm season since the minimum airflow is too high when the supply air temperature is low and cooling loads in the space are at a minimum (Arens et al. 2015). This causes zones to hover at the zone heating setpoint temperature (or below it for those without reheat coils) causing discomfort in warm weather when lighter clothing in worn.

A new VAV box control logic was developed to address these issues of thermal discomfort and energy waste, called dual maximum control logic. This new control logic requires both a maximum cooling and heating setpoint to be specified, whereas the outdated single maximum logic requires only the cooling maximum to be set, and the heating airflow to be the same as the cooling and deadband minimum, which is a function of the cooling maximum (Taylor et al. 2012). Dual maximum logic allows for lower cooling minimum airflows since the heating loads can be met by ramping up to the maximum heating airflow, rather than only ramping up the reheat coil water flowrate.

Allowing VAV boxes to employ the dual maximum logic and reduce cooling minimum airflow rates saves significant energy compared to conventional VAV controls. To demonstrate this, a previous study corrected the minimum airflow rates (while maintaining the same minimum outdoor air flow at the air handlers) in over 1,000,000 ft2 (92,903 m^2) of office space in the Bay Area and measured between 10-30% HVAC energy savings while measurably improving thermal comfort (Arens et al. 2015). Consequently, ASHRAE Standard 90.1 (in 2019) and Title 24 (in 2022) were updated to require minimum airflows to match ventilation air requirements. Even though correcting VAV minimums is energy-efficient, code-required, and cost-effective, the practice is not yet widespread in new construction and the issue persists in most existing buildings. A study focused on quantifying the thermal comfort improvement of 7 offices located in Sunnyvale or Martinez, California found the dissatisfaction rate associated with high VAV minimum operation was decreased by 47% when low minimums were adopted (Paliaga et al. 2019).

In addition to increased reheat and fan energy caused by high VAV minimums, there are often issues with boiler operation that, in many cases, can be easily fixed to reduce energy waste. Some of these issues include piping distribution losses, 24/7 boiler operation, high heating hot water supply temperatures, and boiler short-cycling at low part loads (Raftery et al. 2023), (Raftery et al. 2018), (Lamon, Raftery, and Schiavon 2022).

This project aims to increase awareness about how gas consumption data can be used to inform decisions about pursuing low-cost controls retrofits to correct high VAV minimums or other common boiler operational issues. To demonstrate this, we developed a screening method that can be used by building owners or operators to output a recommendation on whether the building may be a good candidate for a low-cost retrofit to correct these issues, with a specific focus on high VAV minimums.

2 SCREENING METHOD DEVELOPMENT

The screening method developed was intended to be applied to small data sets containing information on buildings managed by the same entity, where it is feasible to communicate with the building operator(s). To develop this method, we obtained a data set containing information on building size, type, and age, as well as over 10 years of monthly gas consumption data, for 22 buildings on the California State Polytechnic University, Humboldt campus. We filtered the data set down to a list of buildings likely to have high VAV minimums or general heating plant control issues and the infrastructure necessary to fix them. The filters used in this method rely on the building operator to provide high-level information about the HVAC and automation systems. By leveraging a strong connection with the building operators at Cal Poly Humboldt we were also able to then validate the filtering process by reviewing the floor plans and schedules to confirm high-minimums were present. Figure 1 shows a graphical representation of the screening method. Subsequent sections describe these filters in greater detail.

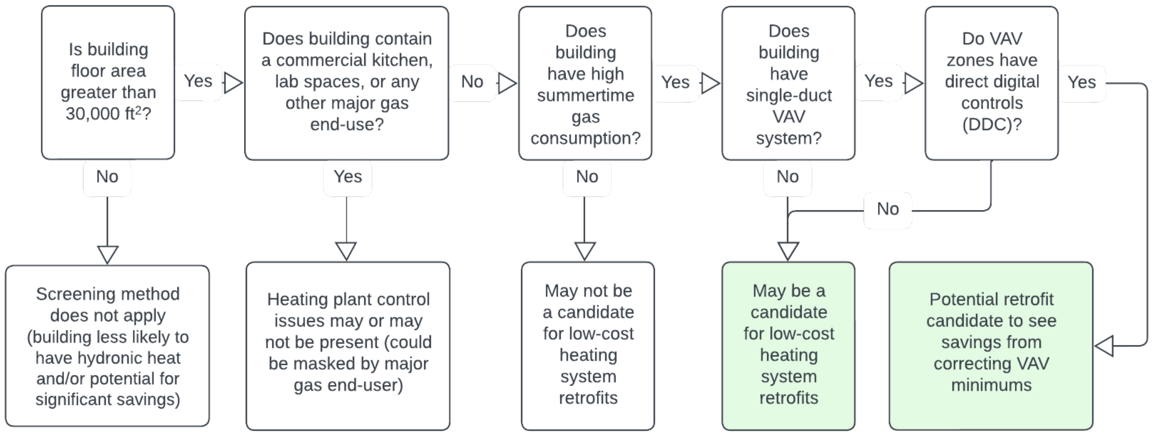

Figure 1: Screening method flowchart

The screening method applies to cases where communication with the building operator is possible. However, there are many scenarios where it may be useful to filter a much larger data set, with less relevant information immediately available, to make broad suggestions on retrofit recommendations. For example, if a utility program is exploring efficiency opportunities it might be useful to know how many buildings could be affected by implementing certain interventions and how large the savings could be. At this scale, it is infeasible to contact building operators to gain information about the HVAC systems. To address these challenges, we adjusted the above filtering method to use only accessible data yet still provide an accurate picture of which buildings would benefit from low-cost heating system retrofits. This adaptation of the screening method is designed to filter for buildings with a broad range of heating plant inefficiencies, rather than solely focusing on VAV minimums. The adapted method was developed by testing the filters on a data set containing information on over 3000 buildings in Washington, DC. This paper describes one example of how the screening method can be adapted based on what data is available. It is likely that using this screening method on other data sets would require adjustments given the available information and individual needs.

The screening method is intended to be a first pass tool to decide if more investigation into the issues would be worthwhile to pursue. This is because it will not select every building that may employ high VAV minimums or other control issues, as some of these operational flaws may be masked by large non-HVAC gas end uses such as commercial kitchens or lab facilities. This limitation, and others, will be discussed in Section 6.

3 SCREENING METHOD DEVELOPMENT

Before beginning the screening process on the Cal Poly Humboldt data set, we identified and excluded any outliers from the raw data by using the median absolute deviation method. If any month in a year of data for a particular building contained an outlier, the entire year was discarded as trust in that year of data was questionable. Then, the first step of the filtering process was to exclude buildings smaller than 30,000 ft^2 (2787 m^2). This was done because the energy savings for smaller buildings would not be as impactful as for larger buildings. Another challenge with smaller systems is that they are more likely to have a DX cooling system, and reducing VAV minimums often runs into a conflict with minimum flow requirements for DX cooling coils. This first filtering step reduced the number of buildings in the data set from 22 to 14. We then consulted the facilities manager at Cal Poly Humboldt to understand which buildings from the data set had the characteristics associated with high minimums and the potential to correct them. We first excluded buildings with large gas end-uses, such as a commercial kitchen or lab space, as it would be impossible to differentiate gas usage caused by heating plant inefficiencies or a large end-user. We found 6 buildings had large gas end-users so they were removed from the shortlist, resulting in a final count of 8 buildings to further investigate.

3.1 Lower-Bound Gas Consumption Threshold Calculation

In a building without the problem of high VAV minimums or other heating system inefficiencies, as long as there is no other large gas end-use, summertime gas usage should be very low in a well-designed and operated building. For buildings with gas-fired heating plants, high VAV minimums are often associated with unreasonably high summertime gas usage due to the excess reheat loads and other heating plant issues that can drive gas consumption up year-round. As such, we developed a lower threshold for summer gas consumption using typical design parameters, assumptions, and previous case study results. The lower bound threshold depicts the highest monthly gas consumption normalized by floor area which a building could reasonably have before it could be suspected of having high VAV minimums. The threshold can also be used to detect buildings with heating system inefficiencies in general. This limit was calculated by using common assumptions to determine how much gas would be required to reheat the minimum VAV flowrate, assuming the minimum flowrate was calculated from the max cooling flowrate. The maximum cooling capacity was assumed to be 400 ft^2/ton (11 m^2/kW), then the max cooling airflow was determined by assuming the air-handling units would be sized to have a flowrate of 350 cfm/ton (47 L/s·kW) of cooling capacity required. The minimum VAV airflow was found by taking 30% of that value. The lower bound threshold was calculated assuming the buildings it would be applied to would mostly employ VAV systems, which is why the minimum VAV airflow was used in the calculation. This is a limitation if buildings with a different ventilation system are referenced to this baseline and will be discussed further in the Limitations section. Once the minimum flowrate was established, the gas required to reheat the air from a low bound cooling supply air temperature, 53°F (12 °C), to a typical zone heating temperature setpoint of 70°F (21 °C) could easily be calculated using Equation 1.

$$\dot{q}_{ahu} = \left(\dot{V}_{min}\rho c_p \Delta T \times \frac{60\ min}{1\ hr}\right) \times 0.3 - \dot{q}_{plug+lighting} \qquad (1)$$

Where $\dot{q}_{ahu}$ is the energy consumed by the AHU in BTU/hr·ft^2 to reheat the air, ΔT is the temperature difference between the supply and reheat temperatures, $\dot{V}_{min}$ is the minimum VAV airflow rate in cfm, c_p is the specific capacity of air, which is 0.24 BTU/lb°F (1.005 kJ/kg·K), and ρ is the density of air, which is 0.07967 lbs/ft^3 (1.28 kg/m^3). A factor of 0.3 was applied to account for the fact that only 30% of zones would typically require reheat, since zones with high heat gains almost always require cooling. A conservative, diversified estimate of the heat from plug and lighting loads, $\dot{q}_{plug+lighting}$, was subtracted from the value, assumed to be 0.8 BTU/ hr·ft^2 (2.5 W/m^2).

Equation 2 shows how the monthly lower bound summertime gas consumption, $\dot{Q}_{lower\ bound}$ was calculated, where $\dot{q}_{dist\ losses}$ is the average distribution loss rate per hour, assumed to be 0.4 BTU/hr·ft^2 (1.3 W/m^2), and ε_{boiler} is the boiler efficiency, assumed to be 80%. The estimate for distribution losses used in this calculation was the average loss rate recorded by a study which measured distribution losses in 7 commercial buildings across 2 climate zones in California (Raftery et al. 2023). Operating hours of both the boiler plant and ventilation system were assumed to be 24 hours per day and 12 hours per day, respectively, for 30 days each month. The only building where the ventilation system also operated for 24 hours a day was the Student & Business Services (SBS) building, so the lower bound threshold was re-calculated when analyzing the gas consumption for this building.

$$\dot{Q}_{lower\ bound} = \frac{1}{\varepsilon_{boiler}} \times \left[\left(\dot{q}_{dist\ losses} \times \frac{24\ hr}{day} \times \frac{30\ days}{month}\right) + \left(\dot{q}_{ahu} \times \frac{12\ hr}{day} \times \frac{30\ days}{month}\right)\right] \qquad (2)$$

The lower gas consumption threshold was calculated to be 700 BTU/month·ft^2 (2.2 kWh/month·m^2). This value was validated by comparing it to the case study results from a project that retrofitted a VAV system with dual maximum logic and recorded the pre- and post-retrofit monthly gas consumption. The area normalized July gas consumption for the post-retrofit case study building, located in Redwood City, CA, was 714 BTU/month·ft^2 (2.3 kWh/month·m^2) (“Advanced HVAC Controls Case Study - 555 County Center” 2019). This demonstrates that buildings with summertime gas consumption above the calculated value of 700 BTU/month·ft^2 (2.2 kWh/month·m^2) may be likely to employ high VAV minimums or exhibit other control issues. The lower bound threshold was re-calculated to be 1000 BTU/month·ft^2 (3.2 kWh/month·m^2) for the SBS building with a 24-hour operating schedule. However, these numbers are just approximations that could begin to point to inefficiencies of the heating system, and many other factors should be considered before a recommendation is made.

Of the 8 buildings remaining after the first 2 filtering steps, all had July gas consumption above the lower bound threshold. Before we moved on to the filters specific to high VAV minimums, we flagged all these buildings as likely to be operating the heating system inefficiently and a candidate to mitigate the issues with simple fixes.

3.2 High VAV Minimums Filtering

The list was then further narrowed to show which buildings could be considered for a retrofit to correct high VAV minimums specifically by considering 2 more filters. Only buildings with a single-duct VAV system were kept on the list, as the issue of high minimum flowrates is not relevant to buildings constant volume systems. While dual-duct systems can be associated with high VAV minimums, these systems are not the focus of this study since they are much less common than single-duct systems and can use less gas when reheating since recirculated air is used rather than primary supply air. We also had to remove buildings from the shortlist that did not have a modern automation system consisting of direct digital controls (DDC) at the zone level, as these buildings would be difficult to retrofit with corrected flowrates even if they did employ the outdated VAV control logic. The facilities manager confirmed 2 of the remaining buildings on the shortlist have single-duct VAV systems and zone-level direct digital controls. Figure 2 shows the gas consumption data for the SBS building, one of the finalist buildings, since it was the worse gas consumer out of the 2 finalists. Also shown on Figure 2 is a non-finalist building, Gist Hall. This building is shown for comparison against the SBS building since it does not have a single-duct VAV system but also has gas consumption well above the lower-bound threshold in the summer months, indicating a clear problem with the heating system. The lower bound threshold is represented by the black line across the bottom of the graph.

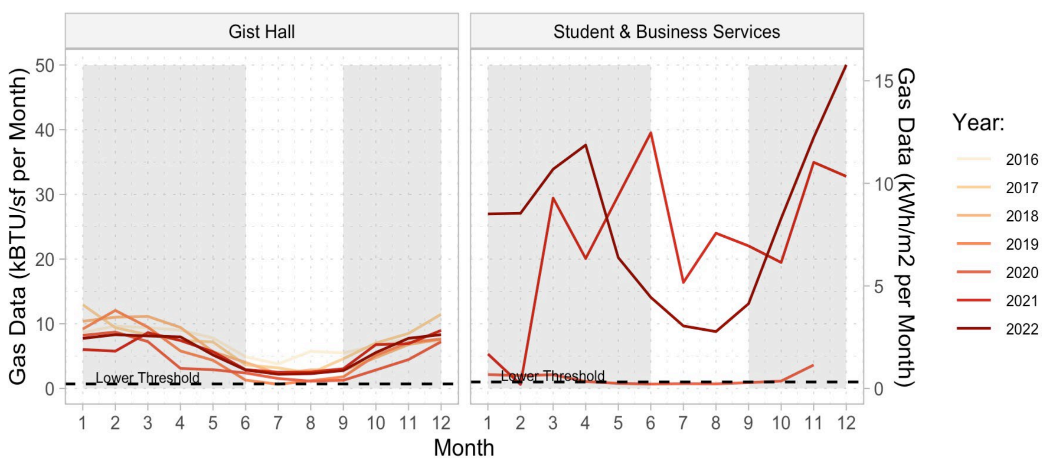

Figure 2: Monthly Gas Consumption Normalized by Area for Finalist Buildings

3.3 Cal Poly High VAV Minimum Flowrate Confirmation and Correction

Lastly, we reviewed floor plans and schedules to verify the presence of high minimums in the candidate buildings. For both the Wildlife & Fisheries and SBS buildings, the drawings showed the minimum VAV flowrates were 30% of the maximum, if not even higher. For the SBS building there were some instances where the minimum flowrates were higher than 60% of the cooling maximums. This investigation of the building drawings confirmed the case of high minimums was present and validated the screening method's capability to correctly select candidates.

Since the SBS was the worst case out of the 2 candidate buildings, this building was selected to demonstrate the potential energy savings if the high minimum flowrates were corrected. Since it is infeasible to accurately model the whole building energy savings, we instead made a comparison between the pre- and post-corrected VAV minimum flowrates for one floor of the building to give context on the potential airflow reduction and associated fan, cooling and reheat energy savings. To make this comparison, we calculated the correct minimum flowrates for Level 3 of the building by following the California Title 24 ventilation requirements (Commission 2022). The pre-corrected flowrates currently implemented on level 3 are 7200 cfm (3398 L/s), with an overall floor area of 9300 ft^2 (864 m^2). Since level 3 consists of mostly office space, the corrected flowrates calculated by following the 2022 Title 24 ventilation requirements are only 1430 cfm (675 L/s). This represents an 80% reduction in minimum airflows if the corrected flowrates were implemented in the building, which would lead to tremendous energy savings by avoiding excess reheating and fan power for unnecessary recirculation.

By estimating the airflow savings from correcting high minimums first, a building owner can determine whether the retrofit would yield substantial enough energy and operating cost improvements before committing more resources to the task. In this case, the building drawings were available to confirm the case of high VAV minimums and that the savings would be substantial enough to pursue a simple retrofit to correct them. There may be other cases where high VAV minimums are suspected but the drawings are unavailable or difficult to access to estimate the corrected savings. If so, the Title 24 corrected flowartes can be estimated by taking the entire area of the floorplate and assigning a general minimum ventilation requirement, such as that of an office (0.15 cfm/ft^2, 0.76 L/s·m^2). While this crude estimate will be less accurate than following the code exactly, it should give a ballpark estimate to help inform whether more work is worth pursuing. For the case of the SBS building, this method differed from the code requirements by less than 3% and the corrected flowrates were calculated to be 1397 cfm (659 L/s).

4 ADAPTED SCREENING METHOD FOR LARGE DATA SET

Like the original method, the adapted method uses building size and gas consumption in the filtering process. This method was then adjusted to only require easily accessible information about building type and age as proxies for the filters from the original method that depend on building operator input. To apply this method, we analyzed a public data set containing the 2019 monthly gas consumption data for 3318 buildings in Washington, DC ("Building Energy Benchmarking" 2019). First, buildings with zero gas consumption in January were eliminated as these buildings may have all-electric heating systems or erroneous data collection, leaving 748 buildings as the true starting point of the filtering process. Then, similarly to the initial method, the data set was filtered to exclude buildings smaller than 30,000 ft^2 (2787 m^2), which reduced the data set to 669 buildings. Certain building types likely to contain large gas users were filtered out, since the building operators were not available to provide that information directly. These building types were hospitals, hotels, multi-family housing, grocery stores, manufacturing facilities, and fitness centers reducing the data set to 255 buildings. Then, we used the same lower bound on monthly gas consumption normalized by building floor area to compare against the July gas consumption for each of the shortlisted buildings to determine which may have heating system inefficiencies such as high VAV minimums. We also calculated an upper bound monthly summertime gas consumption filter to remove any buildings with such high gas consumption they must have a gas-end user but slipped through the building type filters.

This upper bound threshold was calculated in the same way as the lower bound filter to be 3000 BTU/month·ft^2 (0.03 therm/month·ft^2, 9.5 kWh/month·m^2), with worse assumptions made for some of the variables (24/7 operation, 50% VAV minimums, upper bound distribution losses, and 40% floor area in reheating). The last filter is only relevant if looking specifically for high VAV minimums and can be excluded if general heating plant issues are the focus. Rather than filtering out buildings with outdated automation systems by discussing with the building operator, buildings constructed before 1990 were excluded since it was assumed their automation systems are more likely not to be modern enough to make the system upgrades easily. The general shortlist consisted of 23 buildings which was further reduced to 6 buildings after applying the last filter specific to the issue of high VAV minimums. Figure 3 shows the monthly gas consumption data for buildings constructed after 1990 suspected to have heating plant issues. For comparison, this plot also shows the gas consumption of 5 office buildings which have low summertime gas consumption. Many of these buildings do not consume any gas during the summer months, indicating the full shutoff of the heating system over the cooling season. The screening methods described have limitations that may lead to flagging buildings without any issues, or neglecting to select ones that do. These will be discussed in Section 6.

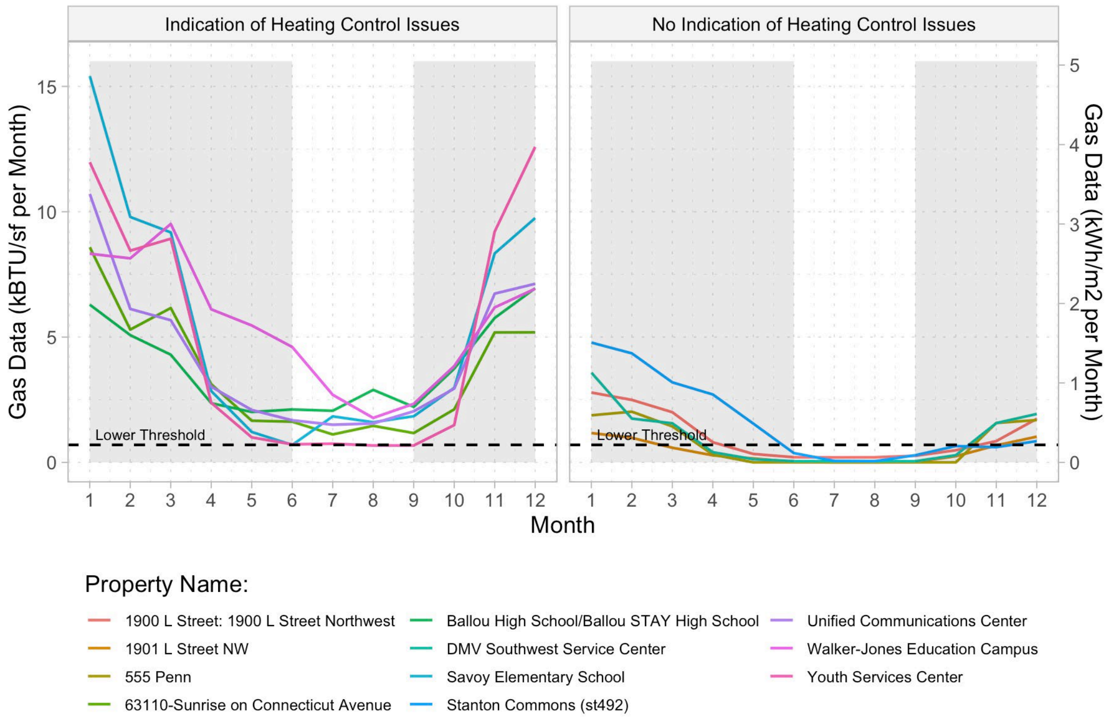

Figure 3: Monthly Gas Consumption Normalized by Area for Finalist and Low-Consumption Buildings

5 NEXT STEPS AFTER PRELIMINARY FILTERING

The initial filters tested on the Washington, D.C. data set were designed to highlight the largest gas consumers most likely to have issues so they could be prioritized over less likely candidates. Of the initial 748 buildings, 23 were highlighted to be retrofit candidates, a shortlist small enough for building operators to manually investigate further. This is a positive result since the initial number of buildings would otherwise have been overwhelming to manually sort through. If 23 is still too large of a number to start with, the further filtered list containing only buildings suspected of high VAV minimums could be prioritized as there is also some indication of what the specific issue(s) could be. However, of the 725 buildings that were initially filtered out, many could have heating plant inefficiencies or high VAV minimums. This section aims to provide suggestions on relaxed filtering methods which could be used after the preliminary filters have been deployed to target more buildings after the first priority buildings are addressed.

The first way to relax the preliminary filters used is to reduce the lower threshold for acceptable summertime gas consumption. We demonstrated this process by assuming the minimum VAV flowrate, an input to the calculation of the lower bound gas consumption threshold, to be 20% of the maximum instead of 30% of the maximum, as was assumed for the initial filtering. This 20% value was selected for these subsequent filtering steps because it was the largest value allowed by Title 24 and ASHRAE 90.1 for the VAV minimum between the time dual max logic was required (mid 2010s) until the most recent versions of these codes which reduced the VAV minimums to the ventilation rate. This means that the reduced lower bound threshold will catch all the buildings that may have minimum flowrates lower than those caught by the first stage filtering, but still higher than what they could be to still maintain code-required minimum airflow rates. Applying the new lower bound filter to the list of 232 buildings that were filtered out due to their "low" gas consumption initially yielded an additional 21 buildings. Additionally, 2 more buildings were added to the shortlist of buildings suspected of having high VAV minimums. There could be many more ways to relax the filters to reveal more buildings to investigate. These could be relaxing or eliminating the building automation or floor area filters, investigating buildings with large-gas end-users for issues that might be masked, or further reducing the lower-bound threshold by adjusting some of the assumptions that were made.

6 LIMITATIONS

One major limitation with these screening methods is that the lower threshold for summertime gas consumption is based on broad assumptions and simplifications. The lower bound threshold does not consider variation in internal gains from occupants or plug loads, both of which vary greatly between building types. The assumption about the maximum cooling capacity may be inaccurate for some buildings or climate zones. Additionally, the assumption that 30% of zones would require reheating is a rough estimate, as the range for this value is so broad and fluctuates throughout the day depending on many factors. However, the value used is intended to be conservative so only the highest priority buildings are highlighted to start with. The threshold is also calculated by assuming a constant boiler efficiency, when in reality it varies depending on the load, particularly when boilers short-cycle, and boiler type.

The lower bound threshold is also limited in that it was calculated assuming the buildings would all have a single-duct VAV ventilation system. While the filters applied attempt to eliminate buildings less likely of employing a single-duct VAV system, the lower bound threshold may still be used to benchmark buildings using a different ventilation system in this filtering method. This is technically inaccurate, but the result is that those buildings still have high summertime gas consumption even if they are referenced to a baseline applying to buildings with single-duct VAV systems. If high minimums are not the issue, this hints that another aspect of the heating system is. This lower bound was used as a critical filter to determine the shortlist of buildings and could be falsely neglecting or including some buildings that do not match the assumptions made.

Another limitation is that because the screening methods were designed to identify the best candidates to start out with, many buildings which could experience savings may be neglected if they have large gas end-users or an associated building type. Once the priority buildings selected by the screening tool are addressed, it may be of interest to relax the threshold values (or remove some filters), or manually check the buildings that were initially discarded.

While the original screening method offers more accuracy in detecting high VAV minimums, since the building operators can offer specific information about the systems, the method adapted for the Washington, DC data set uses coarser filters therefore reducing accuracy. The adapted method is best suited for applications where excess heating consumption issues in general are the focus. However, when looking at buildings flagged for general issues, the operator would have to investigate several issues to determine the culprit, which could be cumbersome and time consuming. Lastly, the screening methods do not quantify the potential savings of the shortlisted buildings. While a building may be flagged as being a retrofit candidate, the savings may not be that large.

7 CONCLUSION

We believe this work demonstrates the potential to identify inefficiencies in many existing buildings, offering owners the opportunity to correct them thereby reducing costs, improving thermal comfort, and avoiding excess fossil fuel combustion. The main idea is to leverage monthly utility bill gas consumption in the summertime to screen for candidate buildings. The first filtering method was successful at narrowing down a data set of 22 buildings to 2 which could be prioritized for a simple, cost-effective retrofit to correct high VAV minimums. Correcting the high VAV minimums showed an 80% reduction in airflow rates, which would correspond to substantial energy and cost savings.

Analyzing the Washington, DC data set demonstrated how a large sample of buildings can be quickly analyzed to determine the priority candidates which can be further investigated for heating system inefficiencies or high VAV minimums. While this adapted method could not be validated in the same way the original screening method could be, it still demonstrates potential to highlight buildings which could benefit from low-cost retrofits at large.

The methods detailed by this paper can positively identify candidates for low-cost controls improvements that yield substantial savings and increase awareness about this issue. By developing this screening method, the hope is that owners will correct the issues and obtain substantial savings at a low cost. To allow building owners and operators the ability to interact with these screening methods, future work is required to develop them into an online screening tool which ingests building information and gas consumption data and outputs a retrofit recommendation.

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