U.S. Commercial Building Stock Analysis of COVID-19 Mitigation Strategies

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Topic: COVID-19, Pandemic and Epidemic

U.S. Commercial Building Stock Analysis of COVID-19 Mitigation Strategies

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SUMMARY

The COVID-19 pandemic highlights the importance of improving building indoor air quality to reduce occupants' chances of contracting airborne illness. The ASHRAE Epidemic Task Force (ASHRAE-ETF) released several COVID-19 mitigation strategies at the onset of the pandemic. This study explores four of those recommendations for reducing transmission of COVID-19 inside buildings: (1) 100% outdoor air ventilation, (2) MERV-13 or better filters, (3) demand control ventilation removal, and (4) HVAC flushing mode. These recommendations were simulated and assessed using ComStock, a model of the U.S. commercial building stock. The study showed the 100% outdoor air ventilation recommendation had the largest impact on energy consumption. Removing demand control ventilation had the smallest national aggregate impact, installing MERV-13 filters led to slight increases in energy use, and HVAC outdoor air flushing led to modest energy use increases.

INTRODUCTION

Energy-efficient buildings provide shelter, comfort, and a healthy environment to occupants while minimizing environmental impact. Meeting the U.S. goal of achieving net-zero greenhouse gas emissions economy-wide by 2050 will require that buildings are efficient as possible.

The COVID-19 pandemic challenged building operators to reduce the spread of SARS-CoV-2 (2019-nCoV), an airborne pathogen spread by human-to-human transmission via respiratory particles. In March 2020, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) convened its Epidemic Task Force (ETF) to recommend building operation strategies as part of its COVID-19 response. In May 2020, ASHRAE published an article about building operations during the COVID-19 pandemic by Lawrence J. Schoen [1]. Based on the information available at the time, Schoen recommended increasing outdoor air ventilation by both disabling demand-controlled ventilation (DCV) and leaving outdoor air dampers open, running systems constantly, and installing filters with a minimum efficiency reporting value (MERV) of 13 [1].

Implementing these recommendations across the U.S. commercial building stock (stock) can substantially impact energy consumption. Quantifying the energy impact of these strategies nationally is informative to the U.S. COVID-19 response. Therefore, the research question guiding this analysis is *What are the aggregate energy impacts of implementing COVID-19 mitigation strategies in HVAC systems recommended by the ASHRAE ETF across U.S. commercial buildings?*

METHODS

ComStock

ComStock is a U.S. Department of Energy modelling platform for the stock developed by the National Renewable Energy Laboratory [2]. ComStock models the energy behaviour of the stock through a series of probability distributions of key building characteristics and features informed by several public and private data sets relevant to energy modelling, such as building type, size, vintage, and HVAC system type [3]. These probability distributions inform approximately 115,000 unique OpenStudio energy models that reflect the variety and frequency of key building characteristics. The OpenStudio models are then simulated and the results scaled to match the floor area of the stock per building type. ComStock results include energy consumption across fuel streams, end uses, and several stock segmentations. *Figure 1* summarizes the ComStock workflow.

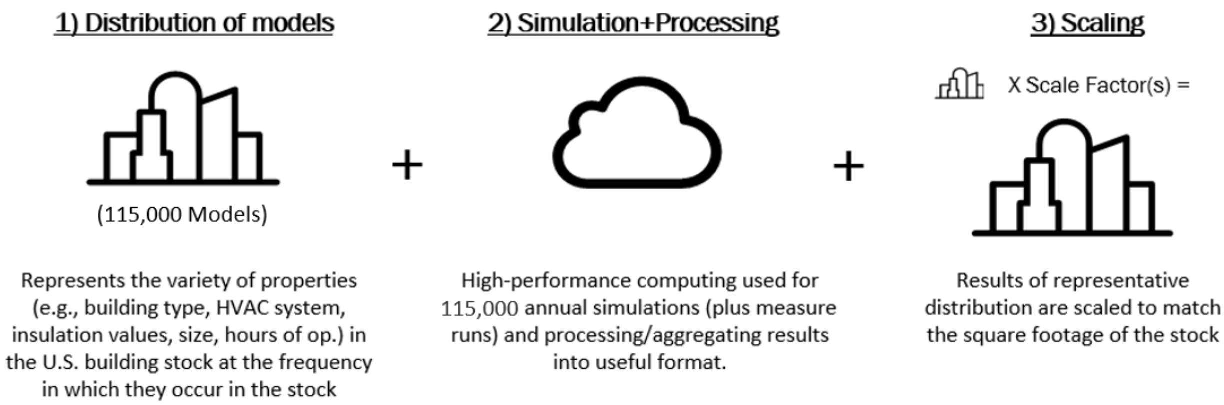

Figure 1. Summary of the ComStock workflow

To quantify the potential impact of pandemic-mitigation recommendations, we used ComStock to analyse the stock-wide energy impacts of implementing HVAC COVID-19 mitigation strategies. ComStock can model energy conservation measures, component faults, or other alterations to building systems/characteristics, and compare these changes to the baseline to understand the energy impact [2]. This study utilized metrics such as energy by fuel type (e.g. gas, electricity) and end use (e.g., heating, cooling, fans) for insightful results reporting. Additionally, results were aggregated by building type and climate zone for further insight and observation. Figure 2 summarizes the distribution of buildings by type and climate zone for this work.

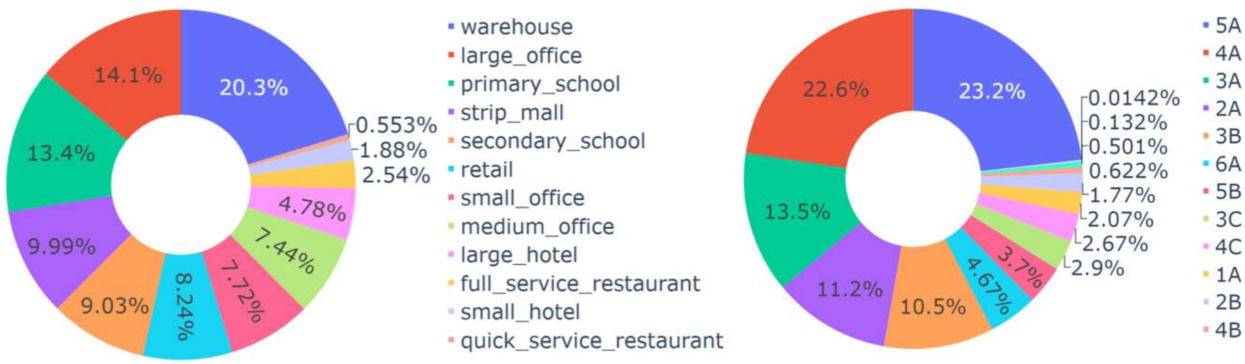

Figure 2. ComStock area breakdown by building type and climate zone

Strategy Selection

Based on the recommendations in the Schoen ASHRAE article [1], we used ComStock to calculate the energy impact of four strategies:

- Replace existing HVAC filters with MERV-13 filters on air handling units (AHUs) (MERV-13 filter upgrade)
- Disable existing DCV, which will not allow systems with DCV to reduce outdoor air below design levels during occupied hours (disable DCV)
- Increase minimum outdoor air ventilation during occupied hours in AHUs (AHU 100% outdoor air)
- Flush the building pre- and post-occupancy for a period of 2 hours at a rate of at least 3 air changes per hour (ACH) of outdoor air (AHU outdoor air flushing).

We modelled the four strategies below through OpenStudio measure scripts written in Ruby. Measure scripts are necessary to automate the application of the required strategy features to hundreds of thousands of unique OpenStudio energy models.

MERV-13 filter upgrade

The ASHRAE-ETF recommends replacing existing AHU air filters with a MERV-13 rating or higher to reduce the risk of SARS-COV-2 aerosols being recirculated through a building's HVAC system. For this study, only central AHU HVAC types were applicable for the MERV-13 strategy. Zone-level terminal HVAC equipment such as packaged terminal air conditioners, unit heaters, etc., were excluded, as were AHUs serving zones with few or no people or dedicated outdoor air systems that operate on 100% outdoor air.

To model the replacement of standard existing air filters with MERV-13 or higher, we added a uniform pressure drop increase of 100 Pascals to all AHU supply fan objects because higher MERV ratings are generally correlated to higher pressure drops [4]. ASHRAE 90.1 states pressure drop credits for filters with higher MERV rating; we chose 100 Pascals because it is the difference between the pressure credits allotted for MERV-13 and those allotted for MERV-9 bin. Fan power in the ComStock baseline is set to meet the ASHRAE Standard 90.1 fan power requirements for the appropriate system type and code year; the 100 Pascals of static pressure was added to the supply fan object in addition to the baseline value.

This approach assumes the existing system fans can overcome the added pressure drop and have been balanced to maintain airflow. It also assumes the existing filters being replaced are changed regularly; an old filter may be very dirty and replacing it with a new clean filter, even of a higher MERV rating, may result in a decreased pressure. We did not include these effects in this study.

Disable demand control ventilation

Many HVAC COVID-19 mitigation strategies involve increasing the amount of outdoor ventilation air delivered to spaces. DCV is a strategy intended to reduce outdoor ventilation air in spaces below design rates during times of detected low occupancy [5], but reducing ventilation air, even during times of low occupancy, could increase COVID-19 spread.

For modelling this strategy, we removed DCV controls wherever implemented in the ComStock models. Prevalence of DCV in the ComStock baseline is based on ASHRAE 90.1 code requirements, which are dependent on factors such as design occupant density, code year followed, space size, etc. [5]. However, some buildings install DCV when not required by code, so this approach could underestimate the prevalence of DCV in ComStock.

Air handling unit 100% outdoor air

AHUs for typical commercial buildings, such as offices, will often use 15%–30% outdoor ventilation air, with the remaining portion being recirculated through the system and back to the zones—design ventilation rates will generally be based on ASHRAE-62.1 guidelines [6]. Modifying AHUs to operate with 100% outdoor ventilation air eliminates any recirculated air in the system that could spread virus aerosols throughout buildings; however, increasing ventilation rates generally increases energy consumption as well [7]. For this study, only central AHU HVAC system types (rooftop units, variable air volume, etc.) were determined to be applicable for this strategy, while zone-level terminal equipment such as packaged terminal air conditioners and unit heaters were skipped, as were AHUs serving zones with few or no people or dedicated outdoor air systems that operate on 100% outdoor air

100% outdoor air was implemented in the models by checking the maximum supply air of each AHU during the model sizing run and sizing the minimum outdoor ventilation airflow parameter to match this value. Note that this strategy only affects the minimum outdoor airflow and does not alter the AHU hours of operation.

Air handing unit outdoor air flushing

Operating AHUs to utilize a pre- and post-occupancy flush mode helps ensure the building has been adequately flushed between waves of occupants. The ASHRAE-ETF guidelines called for 2 hours of flushing before and after building occupancy at a rate of 3 ACH or the maximum possible. Similar to some of the other strategies, the flush mode strategy was only applicable to central AHUs and not zone terminal equipment. However, we did implement this strategy in dedicated outdoor air systems. Although they are 100% outdoor air and cannot further increase the rate of outdoor air, the additional 2 hours of pre- and post-occupancy ventilation periods can still be used.

For implementation, we determined the occupancy schedules for the AHUs and extended them for 2 hours before and after occupied times. Next, we determined the zone volumes on applicable AHUs and used them to calculate the outdoor airflow fraction required to achieve 3 ACH of outdoor ventilation air during the flush periods. For multizone systems with variable air volume terminal boxes, we modified the minimum flow fractions to meet the flush requirements.

Strategy Applicability

Each of the four strategies only apply to a fraction of the buildings in ComStock. *Table 1* shows the percent of the floor area applicable for each strategy.

Table 1. Applicability of ComStock floor area per strategy.

Strategy	ComStock Floor Area Applicability
MERV-13 Filters	80%
Disable DCV	3%
AHU 100% Outdoor Air	80%
AHU Outdoor Air Flushing	77%

RESULTS

Results include output for a baseline model of the stock and the four strategies. *Figure 3* presents the results side by side to compare the annual energy consumption by building end use. The AHU 100% outdoor air strategy has a large energy consumption increase (24.5%) because it triples heating load. The AHU outdoor air flushing strategy has a 7.8% total energy consumption increase, and the other two strategies show less than a 1% increase. The disable DCV strategy was implemented in only 3% of the stock (see *Table 1*), accounting for its small impact.

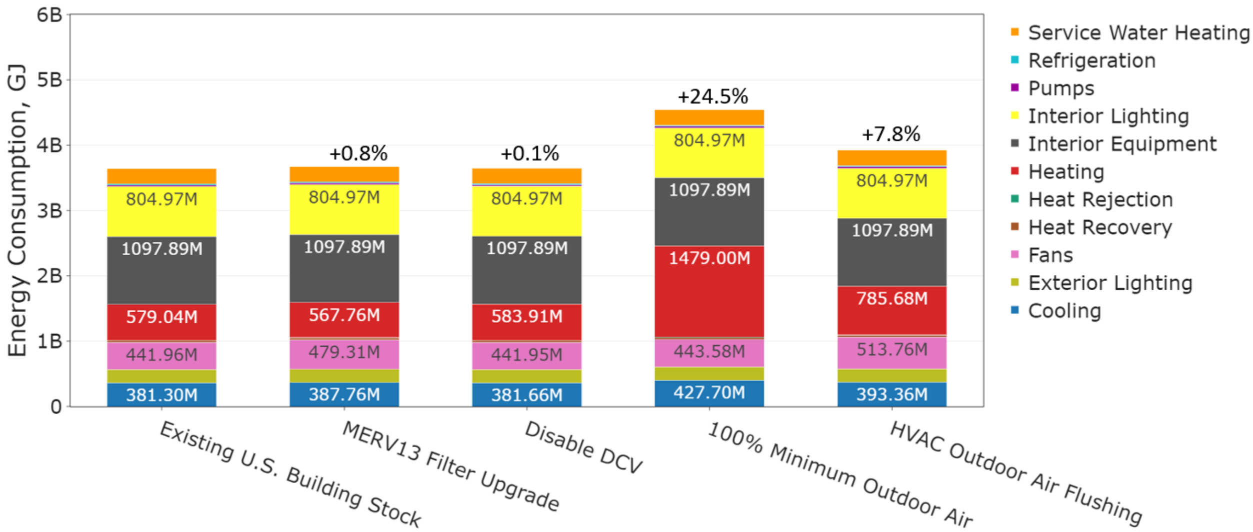

Figure 3. Annual energy consumption by major end use. Percentages shown are savings relative to the existing U.S. commercial building stock baseline.

Figure 4 presents the annual energy consumption by fuel type and shows that the AHU 100% outdoor air results in a 75.2% increase in natural gas and an 8.4% increase in electricity because it substantially affects heating, a major gas end use. The electricity increase is smaller because most electric end uses were minimally or not affected. The same is true for outdoor air flushing.

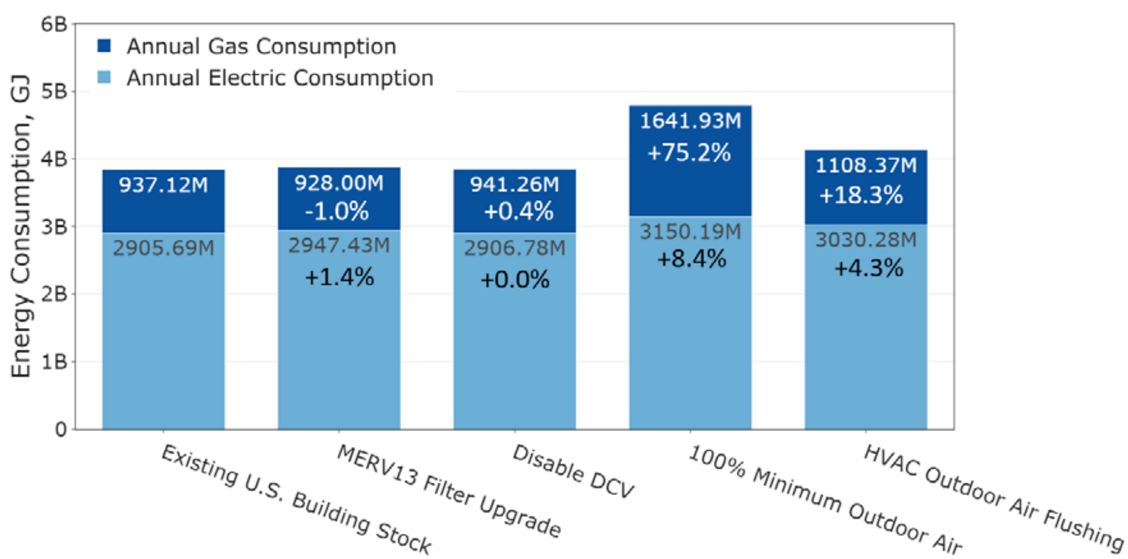

Figure 4. Annual energy consumption by fuel type. Percentages show savings relative to the existing stock.

In *Figure 5*, the AHU 100% outdoor air strategy shows the largest increase (nearly 80%) for climate zone 8 because the percent increase is larger in colder climates. The AHU outdoor air flushing strategy shows a similar trend with a nearly 17% increase in the most impacted climate zone.

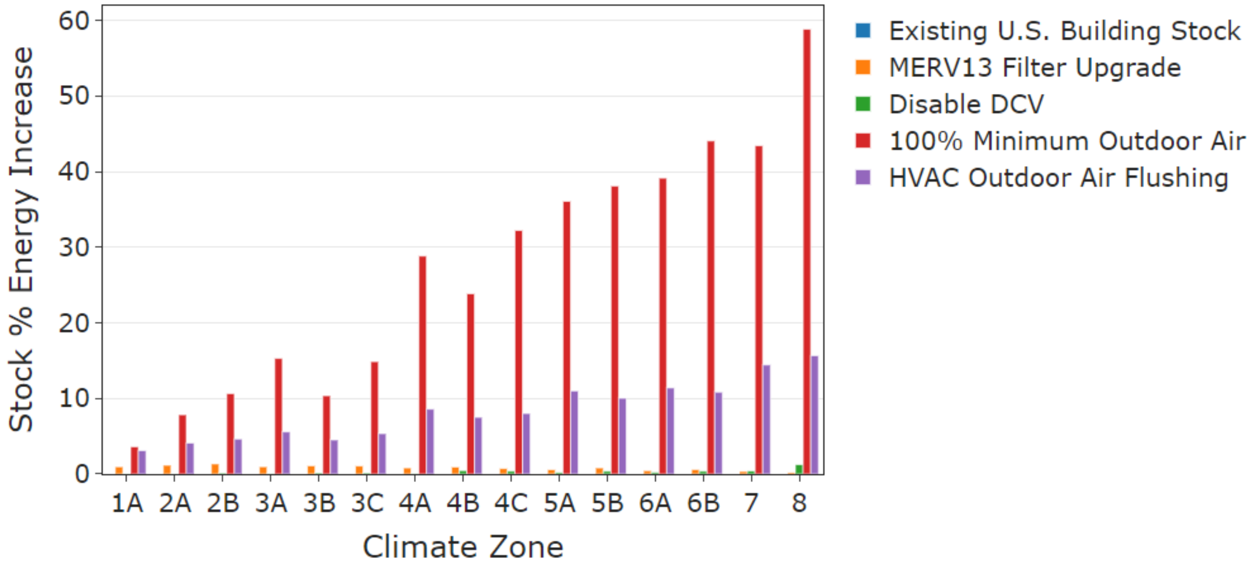

Figure 5. Percent stock savings for each COVID-19 mitigation strategy by climate zone.

In *Figure 6*, the AHU 100% outdoor air strategy shows the highest increase for all building types and exceeds 70% stock energy increase for the small office building type. The AHU outdoor flushing exceeds 10% stock energy increase for several building types. Differences between building types can be explained by the applicability of a strategy to the building type coupled with characteristics inherent to each building type, including HVAC system, design ventilation rates, equipment loads, and hours of operation. Building types with higher internal equipment loads (e.g., restaurants) have smaller percent increases because equipment energy usage is not as affected by these strategies.

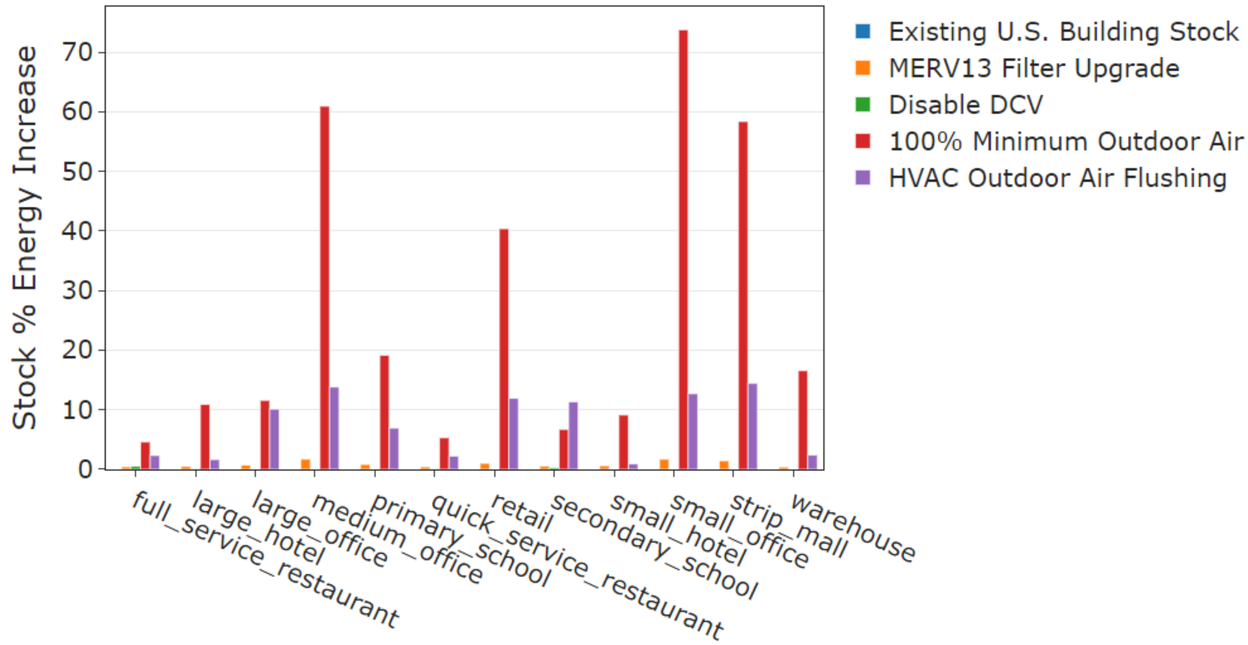

Figure 6. Percent stock savings for each COVID-19 mitigation strategy by building type.

DISCUSSION

Changing the operation of central AHUs to utilize 100% outdoor ventilation air is applicable to 80% of the building stock and results in consumption increases of 75.2% for gas and 8.4% for electricity across the stock. This strategy has the highest energy impact for both gas and electric of all the strategies analyzed during this study. The heating end use (see *Figure 3*) is the most affected, because of the need to condition additional outdoor air, sometimes 4–6 times the baseline, in colder weather. *Figure 5* also shows that energy consumption increase follows a near-linear trend with colder climate zones. In general, building types with smaller design ventilation loads and longer hours of operation would experience greater impacts.

Operating central AHUs with a 2-hour pre- and post-occupancy ventilation flush period is applicable to 77% of the building stock and results in consumption increases of 18.3% for gas and 4.3% for electricity. This strategy results in the second highest increase for both gas and electric energy consumption because of the energy required to condition the additional ventilation air as well as fan energy to run AHUs continuously for 4 additional hours per day (*Figure 3*).

Upgrading existing AHU filters to MERV-13 is applicable to 80% of the building stock and results in consumption increases of -1.0% for gas and 1.4% for electricity. This strategy shows relatively low energy consumption increases and should be considered a low-impact COVID-19 mitigation strategy. The small energy penalty is attributed primarily to the fan end use, with small heating savings due to the additional fan waste heat added to the airstream (*Figure 3*).

Disabling existing DCV controls is applicable to 3% of the building stock and results in consumption increases of 0.4% for gas and 0.0% for electricity across the stock. *Figure 3* shows a small increase in heating and cooling end uses because of the need to condition additional outdoor ventilation air. The relatively low impact is a result of the low saturation of this feature in the ComStock baseline, which drives overall low impact at the total stock level.

CONCLUSIONS

As expected, strategies to mitigate SARS-CoV-2 in commercial buildings contribute to increased energy use, with the greatest increases from conditioning additional outside air for ventilation. Air quality can be improved by using MERV-13 filters with a relatively small energy impact. The ComStock platform models the energy of different strategies across the entire building stock. ComStock can also show impacts of a specific building type or region. Calculations from ComStock provide data to stakeholders including ASHRAE members, states, cities, utilities, policymakers, economists, and researchers, helping them make informed decisions about energy efficiency recommendations, policies, and practices.

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