Health, Well Being and Electrification Retrofits: IAQ Benefits for Asthma Patients

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ABSTRACT

Electrification is primarily driven by reduction of greenhouse gas emissions, to help mitigate climate change, yet there are associated indoor air quality benefits. Unlike outdoor air quality, indoor air quality remains largely unregulated and less studied. Exposure to the pollutants in the home, particularly those produced from gas appliances including PM2.5 and NO2, can be detrimental to human health. Poor or inadequate ventilation can increase concentrations, worsening air quality, and increasing negative health impacts. These conditions disproportionately affect those with existing respiratory conditions and low-income residents.

Asthma exacerbations are largely avoidable, but significant portions of asthma care guidelines are not traditionally covered by Medicaid or included in clinical care. The Asthma Mitigation Program, a pilot in Contra Costa County in northern California where an estimated 4,950 people visit the ER for asthma annually and are disproportionately of lower socio-economic status, tests a program delivery modeling expanding home visiting efforts to include home assessments and remediation services to address social determinants of health from the healthcare, housing, and energy sectors. This pilot, targeting 150 homes, was designed to trial a program model and document benefits to severe asthma patients.

In 2023, 9 homes received pre- and post-retrofit indoor air quality monitoring using Bay Area Air Quality Management District (BAAQMD) grant funds, to quantify changes in indoor air quality that resulted from energy efficiency, asthma trigger and electrification retrofits. This paper will discuss pilot results on program design and documentation of benefits to residents.

Introduction

Health programs and energy efficiency often run in parallel, yet with more studies demonstrating health impacts correlated with conditions in the home, in particular, asthma, there is need to bring these worlds together. With an increased focus on electrification and health benefits, this study evaluates (1) a model of delivering services to severe asthma patients and (2) indoor air quality and health benefits to residents.

Electrification of residential buildings primarily driven by greenhouse gas emission (GHG) benefits refers to transitioning from gas appliances to electric appliances to mitigate climate change particularly when paired with cleaner electricity generation. While indoor air quality benefits are often referred to as non-energy benefits or co-benefits of electrification, , there have been limited studies on quantifying the impacts[1] and fewer programs delivering the

[1] California Energy Commission (CEC) released a grant funding opportunity in 2024 to fund an applied research and development project that will support research to assess the impact of consolidated packages of electrified retrofit

benefits. A significant amount of research and regulation has focused on outdoor air quality, while indoor air quality remains largely unregulated, despite increasing importances for populations spending >80% of time indoors (Colton, 2014).

Therefore, there is a need to increase available data that quantifies indoor air quality benefits of electrification and other measures for known pollutants to increase the strength of evidence of factors exacerbating asthma (Kanchongkittiphon, et al, 2014) and identify delivery models to achieve benefits. This paper will describe the context and rationale for the pilot and summarize results of the pilot designed to evaluate program delivery and benefits.

Background

To understand the pilot context, the following sections will describe: the correlation of housing and health conditions, specifically asthma, benefits of retrofits and electrification, and the regulatory and programmatic landscape in California addressing electrification and health.

Health, Indoor Air Quality, and Exposure

The home environment can present significant physical and environmental health risks and therefore is of interest to understand opportunities to address indoor air quality. Poor indoor air quality is affected by several conditions including behavior, consumer goods, home conditions, appliances, appliance operation, moisture, tobacco smoke, candles, and cooking, and is exacerbated by inadequate ventilation (Zhao, 2021), increasing negative health impacts (Colton, 2014). Outdoor pollutants can impact indoor air quality through increased transmission from poor building envelopes or ventilation systems (Fisk, 2020). Exposure to pollutants in the home, particularly those produced from gas appliances include PM2.5, NO2, formaldehyde, and CO, can be detrimental to health and contribute to poor health outcomes from asthma to cancer.

Particulates. Airborne particles exist in our homes that are small enough to penetrate deep in the lungs, enter the bloodstream, and cause eye, nose, and throat irritation; aggravate coronary and respiratory disease symptoms; increased exposure may even lead to premature death. The majority of indoor PM2.5 originates indoors from cooking, heating, house dust and dust mites. Exposures from these sources including poor range hood operation or use must be studied to inform PM2.5 concentrations, especially for homes of asthma patients (Holm, 2018).

NO_2/NO_x. Nitrogen oxides can act as irritants and may result in acute or chronic pulmonary diseases with continued exposure to high levels. One of the main sources of nitrogen dioxide in homes is combustion appliances. NO2 peaks occur when cooking and, due to proximity of people to the stove, people’s exposure may be high. Research indicates respiratory risk from long term exposure to NO2 for both children and adults (Seals, 2020) and indicates NO2 exposure can lead to premature mortality.

Formaldehyde. Widely used in many products in the home (particularly compressed wood products), formaldehyde outgasses for extended periods and is also a by-product of the combustion process. It causes irritation and, with high levels and extended exposure, increases

measures on air quality and other related impact categories, including resilience to extreme heat, indoor comfort, and energy and cost savings in California homes.

the risk of cancer. Formaldehyde from natural gas stoves is more prevalent when simmering at lower-level flames and pilot lights (Poppendieck, 2018).

Carbon monoxide. This is an invisible and undetectable gas by people produced by incomplete combustion. High indoor CO levels result from poorly vented or operating combustion appliances. CO poisoning can cause dizziness and nausea and can lead to death.

These conditions disproportionately affect those with existing respiratory conditions and/or low-income residents due to exposure as lower income households are more likely to suffer effects from outdoor pollution (Seals, 2020). Disparities in asthma prevalence can be attributed to several factors including lack of access to health insurance, quality of care, increased exposure to triggers (UCLA, XXX). Several studies have demonstrated that higher levels of exposure to traffic related air pollution can increase the risk of asthma and adverse respiratory health impacts on children including lung damage. Ground level of ozone emitted from refineries and cars can intensify adult response to allergens (CARB, 2024). Air pollution can increase the potential of getting asthma or exacerbate asthma (EPA, 2024). Lower income households are more often located in areas of poorer outdoor air quality as shown in CalEnviroScreen[2]. Typical indoor and outdoor asthma triggers and risk for respiratory health include exposure to moisture, mold and dust mites, household allergens, pest allergens, combustion irritants: NO2, CO, PM2.5, PM10 and excess cold and/or heat (Mendell, 2007). Asthma is one of the most common chronic diseases affecting the U.S. population, with 7.7% of individuals having ever been told they had asthma with a higher percentage of the population in lower economic brackets (CDC, 2024) and 15% of the population in California (CDPH, 2024). Ten American die every day from asthma and black Americans are 2-3 times as more likely to die from asthma. There are effective medicines to address asthma conditions and asthma exacerbations are avoidable, yet Medicaid and clinical care do not cover significant recommendations in asthma care guidelines including home-based education and remediation of asthma triggers. Focusing on outdoor pollutants like PM25 as major asthma trigger, may neglect indoor conditions that can be mitigated (Holms, 2018). Evidence continues to point out the indoor air quality impacts on health and identifying recommendations to improve indoor air quality to positively impact health (Wilson et al., 2023).

Benefits of Retrofits and Electrification

Homes that are dry, clean, safe, well-ventilated, pest and contaminant-free, well-maintained, and thermally controlled are healthier for occupants (Thomson et al., 2013). Energy efficiency and electrification upgrades to replace gas appliances, often prioritized to reduce utility costs and GHG emissions, can also have a positive impact on the health of the occupants by improving physical home conditions and conditions of daily life, meeting Thomson's criteria. Two literature reviews of academic work studying the health impacts of energy efficiency improvements found sound evidence that energy efficiency upgrades improved overall health,

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[2] CalEnviroScreen is a mapping tool that helps identify California communities that are most affected by many sources of pollution, and where people are often especially vulnerable to pollution's effects.

respiratory conditions, allergies, headaches, cardiovascular conditions, and mental health due to a reduction in the exposure to pollutants described above that can cause new incidences of disease or exacerbate pre-existing health conditions (US DOE, 2016; E4 the Future, 2016). Measures that can reduce concentrations of pollutants and risks in homes include tight ducts, air sealing and insulation, low emitting materials, properly venting or eliminating combustion appliances, tight envelope, and filters. Tight envelopes can mitigate impact of outdoor pollutants but can increase concentrations of indoor pollutants if there is not good ventilation (Fisk, 2020). These common energy efficiency measures help stabilize temperatures, remove unhealthy gases and particulates from the indoor air, and create a more comfortable living environment. Additionally, there are measures not included in standard energy efficiency programs such as ventilation of living spaces, bathrooms, kitchen, and laundry, carpet removal, moisture mitigation, and consumer goods such as air purifiers that also address asthma triggers.

Several research studies have been conducted on the co-benefits of electrification and air quality pollutant reduction and their associated health benefits (Zhu, 2020; Seals, 2020; E4 Future, 2016; Colton, 2014). A UCLA Study modeled a 3% reduction of CO, NO2, and NOx concentrations can be attributed to gas appliance replacement residential buildings (Zhu et al., 2020). A study of two public housing projects documented reduced exposures to NO2 and PM2.5 and improved health benefits for residents who moved from conventional housing to healthier housing partially attributable to switch from gas to electric stoves (Klug, 2011). Health outcomes in pediatric patients showed a reduced frequency of asthma encounters for homes that received weatherization services (Wilson, et al. 2023). Efforts to increase energy efficiency and electrification can limit exposures, reduce pollutants and increase potential for health benefits.

Programs, Policies and Regulations

California has a diversity of activities such as code, policies, program, and standards to promote electrification with prioritization of equitable electrification. California has adopted legislation and policy goals establishing GHG emission and cleaner energy goals (Legislative Analyst's Office, 2023). This has resulted in regulatory standards and/or programs adopted and administered by California Air Resources Board, California Public Utilities Commission and California Energy Commission. The adoption of the 2022 Building Energy Efficiency standards (2022, CEC) prioritizing all electric new construction sent a strong signal. However, given two thirds of existing housing stock will exist in 2050 and the majority includes combustion appliances, existing homes must be addressed at scale. For buildings, GHG and energy savings have been major drivers of energy efficiency and electrification. That said, California Air Resources Board (CARB, 2022), South Coast Air Quality District (SCAQMD, 2024) and Bay Area Air Quality Management District (BAAQMD, 2024) are evaluating or have adopted zero emission standards for stationary appliances to address air quality. California has numerous programs that support energy efficiency and a growing number focused on decarbonization. These programs include a diversity of measures which quantify savings using metrics such as GHG emissions and/or energy use. A GHG emission reduction metric allows programs to prioritize removal of combustion appliances from homes in conjunction with traditional energy efficiency measures such as air sealing and insulation from homes thus resulting in health benefits. While there are benefits from these programs, they are not designed to comprehensively address asthma triggers.

Study Objectives

The basis of the study was to evaluate the program model providing both home upgrade and health services through a partnership of organizations to households with severe asthma patients to address asthma triggers and the resulting changes in indoor air quality associated with these retrofits. In Contra Costa County, 300,000 residents live in a census tract that ranks in the 95th percentile or higher of asthma emergency department rates statewide, which is the largest number by county in the state and the BAAQMD was ranked third highest in NOx emissions attributed to furnaces, water heaters and stoves, making this region a prime target for these services (Seals, 2020). The pilot started in 2021 to serve 150 low-income sing family or multifamily households in the County with members that have with poorly controlled asthma, as defined as Asthma Control Score of <19 and identified on medical records or health professional referral through partnership of the County Health Plan (CCHP), Association for Energy Affordability (AEA), and County Department of Conservation and Development. This pilot expanded CCHP's base asthma home visit services by (1) Providing referrals for services (2) Including home assessment and remediation services through a partnership with AEA (2) Testing implementation capacity within CCHP to demonstrate a model to address social determinants of health from the healthcare, housing, and energy sectors and (3) Monitoring parameters and documenting health conditions to understand indoor air quality impacts.

The study is attempting to answer the following research questions:

- How well does this model work to engage participants and to reduce pollutants?
- What occurred at each home individually?
- What improvements in health outcomes were experienced by asthma residents?
- What changes in indoor air concentrations of PM and NO2 occurred?
- What improvements can be expected from different home retrofits?

Program Delivery Model

The program delivery originated with home visits by a County Community Health Worker (CHW) and each household received a home goods kit to help address asthma triggers (i.e. mattress covers, HEPA vacuum, air purifiers, etc.) as well as education on behavioral considerations. The CHW referred willing members to AEA for a home assessment. Out that potential pool of 150, 96 homes received virtual assessments for initial screening and to obtain landlord consent. Of those, 32 homes received on site assessments to identify advanced asthma trigger remediation, energy efficiency, and electrification retrofits. AEA defined the scope of work and coordinated delivery of services. Contractors paid by AEA completed the no cost retrofits which were verified AEA. 22 homes received services funded by energy efficiency programs and grants from the Sierra Health Foundation and BAAQMD. Measures delivered through the program included cleaning services, consumer goods, improved ventilation, allergen mitigations such as carpet removal, air filtration, thermal comfort improvements, and replacement of combustion appliances. 15 homes received upgrades and nine of the homes met the criteria for monitoring and received pre- and post-retrofit monitoring and surveys.

Methodology

Only homes that included an electrification measure, improved ventilation, and mitigation of an asthma trigger were monitored, informed by research demonstrating multilevel interventions are needed to effectively reduce indoor PM2.5 and other pollutants (Chu, 2020). Quantitative data, using monitoring equipment and performance testing and measurement was coupled with qualitative data. Monitoring which occurred for two weeks before and after retrofits. Table 1 lists the equipment used for monitoring these targeted pollutants and conditions affecting pollutant concentration in priority location of kitchen and either main living space or bedroom. Not all data points were collected in every home due to the existing conditions and/or scope of work. The study incorporated pre and post retrofit survey data and daily logs to gather qualitative data and quantitative data about the home and resident experience including self-reported health data and data from the health plan when possible. The survey instruments were used to document changes in indoor quality and health as experienced by the occupant. Differences in indoor air pollution are also influenced by behavior. This can be incredibly expensive if not impossible to capture through monitoring. To account for these variations, participants documented specific daily activities during monitoring periods. These data were processed to determine changes in indoor air quality such as reductions in ambient indoor particulate matter and NO2 and improvements in relative humidity and temperature and potential correlation to health impacts from the retrofits. However, because the homes had a combination of home goods, behavioral education, efficiency upgrades, and asthma mitigations to address asthma triggers, it is not possible to directly correlate health impacts to specific upgrades.

Table 1. Matrix of Monitored Data for Associated Equipment

Data source	Data collected	Unit	Measurement equipment
Electrical loads	Data logged circuit level	kW, kWh	Emporia Gen 2 Vue
Indoor temp and Rh	Data logged	˚F, %	eLichens IAQM Pro
Outdoor temp. and Rh	Data logged	˚F, %	Onset HOBO U12 Pro v2
CO2/PM/NO2/O3/ HCHO	Data logged	ppm	eLichens IAQM Pro
NO2	Cumulative	ppm	Ogawa passive samplers
Formaldehyde	Cumulative	ppb	SKC UMEx-100 Passive
Air tightness	Infiltration rate	ACH50	Blower door
Gas cooking	Stove operation	˚F	Thermochron iButton
Bath and range hood ventilation (Vented)	flow rate	cfm	Testo or Retrotec
	operation	min	HOBO UX90 logger

Data Quality

The following describes field activities related to data quality that affected this project.

- Given the timeline and damage to equipment, it was not possible to use the same equipment in the pre and post measurement at each home as intended. Because of the variation in the sensors, the comparisons from pre to post could not always be relied on.
- Equipment was installed in the same location pre and post for each home individually.
- Indoor air quality monitors were assessed between deployments to confirm operation and identify failure. Some issues were missed resulting in deployment of faulty sensors.
- Seasonal variations existed due monitoring spanning February through December. Impacts of excess cold were not captured as monitoring occurred during the cooling season. Seasonal variation impacts HVAC operation, ventilation strategies, condensation, and cooking times that can affect pollutants and affect asthma conditions.
- Various monitoring equipment failure resulted in incomplete data sets in some homes.
- The daily log data set was incomplete due to highly variable completion rates.
- Localized outdoor air monitoring was not included as part of this study.

Results

A total of nine homes were monitored and Table 2 summarizes characteristics of these homes. The upgrades in the homes included a unique combination of measures informed by existing conditions and available funding and therefore not all recommended measures were completed. The pilot was only able to layer funding from one program for limited measures despite the intent to layer funding from various efficiency programs to maximize interventions. The monitored homes received 4-8 measures. Two homes with solar became all- electric. Bathroom ventilation was the most common measure (8), followed by range hoods (7), electrical upgrades (7), HVAC heat pump (6) induction range (5), duct sealing (5), attic insulation (3), HPWH (3) windows (1), minor envelope repair (1) and carpet removal (1).

Table 2. Summary Table of Key Aspects of Monitored Homes

Member ID	Rent or Own	Stories	Beds	Occ.	Square Footage	Bathrooms	Age	Asthma patients
26	Rent	1	3	6	1063	2	1984	2 kids
164	Own	1	3	6	1234	2	1959	2 kids
165	Rent	1	2	7	817	1	1943	1 kid/1 adult
101	Own	1	2	4	1100	2	1980	1 kid/1 adult
166	Own	1	3	2	1173	1	1937	1 adult
25	Rent	1	3	5	742	1	1952	1 kid

103	Own	1	3	5	1472	2	1950	1 kid
88	Rent	1	3	1	1404	2	1972	1 adult
146	Own	2	4	5	1742	4	2014	1 kid

The initial results of the pilot discussed below will cover participation and delivery and indoor air quality benefits across all homes and by homes group by retrofit scope of work.

Participation and Delivery

CCHP engaged with a total of 170 members and through the referral process AEA engaged with 149 members over 3 years, completed 96 virtual visits and 32 site assessments, and provided services to 22 homes with 15 of those receiving retrofits and 7 receiving cleaning services only. This was short of the 38-retrofit goal. Implementation and recruitment were significantly impacted by the COVID pandemic, causing delays and requiring changes to the delivery model. The complexity and time required to complete virtual visits, obtain consent, and complete a site visit is not sustainable. One of the biggest factors that impacted the success of the program was the ability to obtain consent to provide upgrades after a virtual assessment as only 12 referrals were homeowners. AEA received contact information for 37 landlords, AEA was not able to provide services to 62% of these residents due to lack of response (32.4%) or declined participation (29.7%) from the landlords. Overall, a referral from a trusted source was successful in developing relationships and providing services for some members. That said due to staff discontinuity and COVID, 29% of members were not responsive. The following is a brief list of reasons why members did not participate resulting in a reduced pool of participants:

- The member was not interested in upgrades.
- The member said their landlord would not be interested in upgrades.
- No contact was made with member and/or the landlord.
- The landlord refused services.

Indoor Air Quality Benefits

The benefits presented below include a summary of ACT score, NO2 results and PM2.5 for eight of the nine homes followed by a discussion of homes grouped based on similar upgrades to see if there are trends. Member 146 was excluded due to a reduced scope of exhaust fan and range hood resulting in limited data set.

Asthma Conditions. The ACT provides a reference for a point in time and inhaler use and ER visits provide insight into longer trends. Three had improved scores; three had worse scores; one has not taken test; two remained unchanged. For one child with a worse score, the post retrofit ACT was administered when he had been sick for 2 weeks. Asthma ER visits for 12 months post are not yet available.

Table 3. Summary of the Asthma Control Test and ER visits and Inhaler Use.

Member ID	Asthma ER Visits 12 Month Prior	Pre ACT/ Month of Test	Post ACT / Month of Test	Inhaler Use	Days Affected by Asthma
25	0	13 (Dec)	21 (Dec)	Reduced 1/day to 1/month	Reduced 15-21 to 1-3
26	3	16 (Sept)	TBD	Reduced 2/day to 2/week	Reduced 4-7 to 1-3
88	3	9 (Oct)	9 (Dec)	Same 2/day	Same 4-7
101	2	24 (Dec)	18 (Dec)	Same 2/day	Increase 1-3 to 8-14
103	3	14 (Jan)	25 (Dec)	Reduced 4/week to as needed	Reduced 4-7 to none
164	3	22 (Jan)	12 (Nov)	Same 2/day	Increase 1-3 to 8-14
165	2	16 (Oct)	12 (Nov)	Reduced 2/day to 2-4/week	Reduced from 8-14 to 4-7
166	1	21 (Feb)	25 (Nov)	Same limited use	Same

NO2 results. While NO2 results varied per household based on cooking frequency and volume, as shown in Table 3. Reductions were impacted by the fuel source and improved ventilation.

Table 3. Summary of NO2 Passive Samplers Results for Pre and Post Retrofit.

Member ID	Stove - Pre	NO2 (ppb)	NO2 (ppb)	% reduction	Stove - Post	Number of days (pre/ post)
103	Natural Gas	38.7	2.87	93%	Induction	20/14
25	Natural Gas	24.8/ 19.1	5.1	79%	Induction	26/14
165	Natural Gas	41.3	28.1	32%	Natural Gas	15/17
88	Natural Gas	7.83	6.7	15%	Gas & Induction	15/9
164	Natural Gas	39.6	3.6	91%	Induction	15/14
166	Natural Gas	9.88	2.08	79%	Induction	13/10
101	Electric	2.94	2.33	21%	Electric	6/20
26	Electric	4.73	3.92	17%	Electric	26/14

PM results. Table 4 shows the variance in concentrations where PM2.5 increased in one home with induction cooking and homes with new HVAC and duct improvements demonstrated reduction in PM2.5. Member 25 had very low average of 2ppm in post retrofit period. Member 166 had a power outage that resulted in bad data. In subsequent deployments these monitors did not result in similarly low values.

Table 4. Variance in Average PM2.5 concentration with stove and HVAC Configuration.

Member ID	Kitchen Average	Post Stove Type	Rangehood	Living / Bedroom Average	HVAC
103	-34%	Induction	new vented	-41%	ducted gas to HP
25	bad data	Induction	new vented	-57%	PTAC to HP
165	0%	Natural Gas	new vented	-39%	wall furnace to HP
88	-5%	Gas & Induction	none	-79%	ducted gas
164	47%	Induction	new vented	50%	ducted gas
166	bad data	Induction	none	bad data	wall furnace to HP
101	-36%	Electric	vented upgraded	-41%	ducted gas to HP
26	20%	Electric	vented upgraded	-54%	ducted gas to HP

The sections below describe each of the four groups and the expected results for each type of retrofit and what occurred at each home individually.

Group 1. Scope included: Existing electric stove, improved bathroom and range hood ventilation, duct sealing, attic insulation and split heat pump system. Applies to Participants 101 and 26. The key aspects for this group that are expected to change are described below.

Reduction in particulate matter due to sealed ducts when HVAC is operating. Both had a reduction in average PM2.5 and maximum value in living spaces and showed a decrease in frequency of levels above 35ug/m3. Prior to retrofit, Participant 26 was not able to operate the HVAC without negatively affecting child's asthma. Post retrofit operation was twice as much.

Reduction in particulates when cooking attributed to better range hood. Cooking occurred regularly every day throughout the day with greater stove runtime post period. PM2.5 increased for 26 and decreased of 101. Burner operation could not be determined with circuit monitoring.

Reduction in humidity and increased comfort in post retrofit. 26 was more comfortable and operated HVAC twice as much and 101 reported increased comfort with added air conditioning. Indoor temperature was more controlled and stable in post retrofit.

Group 2. Scope included: Induction range replaced gas range, HP HVAC system, improved ventilation either rangehood only, bathroom only or both. Applies to Participants 25, 166 and 103. The key aspects for this group that are expected to change are described below.

Reduction in particulate matter when new HVAC is operating. The participants received three different HVAC systems: PTHP replacing PTAC, ductless minisplit replacing wall furnace, ducted split system replacing gas furnace. For 25 and 103, peak PM2.5 did not align with HVAC operation indicating another source in post. There was no pre retrofit operation for 25 and no data for 101. 166 had data errors with the elichens and no operation of the wall furnace in pre-retrofit period because it was not heating season, had lower PM2.5 concentrations.

Reduction in particulates attributed to better range hood. The OTR for 25 could not be monitored with the existing sensors. For both 25 and 103, cooking odors documented in pre-retrofit survey were not identified by residents post-retrofit. 166 did not receive a rangehood.

Reduction of NO2 and PM2.5 attributed to replacement of gas stove with induction range. The concentrations and peaks for PM2.5 and NO2 were lower in the post-retrofit period. All three residents were satisfied with the induction range.

Group 3. Scope included: Induction range replaced gas range, ventilation for bathroom only or range hood and bathroom, attic insulation and sealed return. Applies to Participants 88 and 164. Key aspects for this group that are expected to change are described below.

Reduction in particulates when cooking attributed to better range hood for 164. There was an increase in average, peak concentrations and frequency above 35ug/m3 in both kitchen and living room. The source is unknown but could be candles, outdoor air and/or air fresheners.

Reduction in NO2 and PM2.5 attributed to replacement of gas stove with induction range. Both homes had an increase in average and maximum concentration of PM2.5. Participant 88 uses incense, candles, aerosols and duralogs for heating that would contribute to higher post-retrofit concentrations. 164 self-reported the kitchen smelled better with induction range.

Reduction PM2.5 attributed to sealed ducts and return. The higher particulate concentrations at 164, does not align with expectations. Participant 88 did not have an operational HVAC system at the final monitoring period. A duct leakage test should have been completed at each of the homes and sensor at register should have been installed.

Group 4. Scope included: Hard surface flooring, new range hood and HP HVAC. Applied to Participant 165. The key aspects that are expected to change are described below.

Reduction in particulates and NO2 concentrations when cooking attributed to better range hood. There was some alignment of peaks of NO2 and PM25 associated with burner use and overall consistent average but a 10% reduction in peak concentration. That said there was a 9% reduction in NO2 from pre-retrofit living room concentrations to post-retrofit kitchen concentration. This cannot be attributed only to the range hood due to lack of data on cooking frequency to compare the two periods of time.

Reduction PM2.5 attributed to replacement of carpet with hard surface flooring. The kitchen pre and post had the same average and 11% reduction in maximum concentration, whereas the living room showed a 39% reduction in average and 43% reduction in maximum concentration. This reduction could have been impacted by the carpet replacement in the living room which allowed the children to play on the living room floor with reduced impact to asthma as reported.

Stabilized indoor temperature. The post retrofit period occurred in August requiring some cooling, the HVAC was used twice for about an hour and a half each time over eleven days.

Reduction in PM2.5 with ductless mini splits compared to a wall furnace. Because neither the pre nor the post monitoring period occurred during heating season this could not be documented.

There are some key takeaways and trends in the results of this small data set to inform research question.

What improvements in health outcomes were experienced by asthma residents? All participants experienced a reduction in medication/ inhaler use or it remained static. The use of medication and/ or ER visits provides insight into longer impacts. 50% experienced a reduction in days affected by asthma and 2 patients had consistent experience. Data on asthma pre and post emergency visits will be interesting to compare. Residents reported increased comfort and increased use of rooms in the home. Stabilized temperatures were consistently noted as improvement and are important as excess heat or cold is an asthma trigger. The increased usability of the home from utilizing space conditioning or child can play on floor without adverse impacts can reduce stress and increase comfort.

What changes in PM and NO2 occurred? Did the program work well in reducing PM and NO2 if we utilize >12 ug/m3 and above 35ug/m3 over 24 hours is unhealthy for PM2.5 and an annual average 0.030ppm according to CARB for NO2? Reduction in PM in living areas were evident in homes with HVAC replacements and distribution improvements and new vented range which reduced indoor disbursement of pollutants when operating. Overall, there was a reduction in frequency above 35ug/m3 in homes, peaks and average concentrations, reducing exposure. Cooking still results in variable PM levels despite fuel type. As expected NO2 went down significantly, 79% - 93%, when replacing gas stove with induction eliminating high exposure. Three homes had concentrations over 15- 20 days that approached or exceeded CARB annual average. Two saw +91% reduction with induction and a range hood and the third a 32% reduction with a range hood bringing levels below that threshold. The homes with electric ranges already had low levels.

Recommendations

Below are recommendations to expand this work to deliver holistic benefits to residents.

Participant and landlord engagement is key to success. Lags between steps in the pilot hurt uptake, participation, and follow-up. Obtaining landlord permission required significant amount of time and had low return on that investment. Engagement with landlords outside of the program delivery can help build awareness and hopefully willingness overtime. Not all landlords are going to be willing to participate and that goals need to be set accordingly.

Program model of delivery of a combination of virtual and site visits must be streamlined to utilize resources more efficiently.

Robust educational materials on benefits of measures and operational aspects to maximize benefits of retrofits are critical. Participants did not always understand the connection between asthma and home conditions and operations. There are several resources that can be leveraged from cleaning guides to induction cooking. HVAC operation will have to be system specific.

Expand measure eligibility and potential for layering funding. This pilot had a limited yet flexible budget to include measures that do not have direct energy or GHG savings. This work has other benefits for residents including stable temperatures, potentially stable bill, less days missed from school or work, less medicine which all have economic. Layering funding from multiple sources is necessary to address mitigation measures not covered by efficiency programs.

Increase connections between health and energy/ home services. There is great benefit in getting referrals from trusted sources to bring benefits to harder to reach populations. Yet, pairing asthma trigger mitigation services and energy efficiency programs with medical programs such as the MediCal CalAIM program will be challenging because of the different models of implementation in different regions. Finding willing partners and experts will enable a team to navigate structural challenges and continue to test delivery models.

Conclusion

Household conditions can exacerbate asthma triggers but can be largely mitigated through targeted home retrofits. Developing and delivering programs that distinctly address asthma triggers and efficiency will result in healthier and more affordable homes. This small pilot identified benefits to severe asthma patients and households as well as participation challenges. Through a second BAAQMD pilot, we hope to scale this work continuing to test monitoring strategies and delivery models. These data will increase opportunities to advance equitable clean energy initiatives, not only to achieve GHG goals but also healthier homes.

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