Environment and Pollution; Vol. 7, No. 2; 2018
ISSN 1927-0909 E-ISSN 1927-0917
Published by Canadian Center of Science and Education

Assessment of a Woodstove Changeout Program on $PM_{2.5}$ Levels in Keene, New Hampshire, U.S.A.

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Received: July 23, 2018 Accepted: August 28, 2018 Online Published: September 13, 2018

doi:10.5539/ep.v7n2p11 URL: https://doi.org/10.5539/ep.v7n2p11

Abstract

In local airsheds, wood smoke from residential woodstoves is a major source of $PM_{2.5}$ pollution. Exposure to $PM_{2.5}$ can cause a variety of health problems and complications. Communities situated in valleys that experience cold winters are especially susceptible to poor air quality during inversion events on calm winter nights. Keene, New Hampshire, USA is one such community where the widespread use of outdated residential woodstoves frequently resulted in $PM_{2.5}$ exceeding national standards. Seeking to improve air quality, the City of Keene partnered with the New Hampshire Department of Environmental Services from 2009-2010 to facilitate a woodstove changeout program which replaced 86 inefficient woodstoves with newer or alternate heating appliances. Despite the fact that many U.S. communities have enacted similar programs, research on their effectiveness is limited. This research assessed Keene's program and determined that Keene has experienced a significant reduction in $PM_{2.5}$ on calm winter nights. When winds are below 2 miles per hour (3.22 kilometers per hour), $PM_{2.5}$ dropped 7% to 52% (1.28 to 7.30 $\mu g/m^3$) after the woodstove changeout; a mean decrease of 23%. It therefore appears that Keene's woodstove changeout program successfully improved air quality on the nights that are most likely to violate national air quality standards. This provides evidence that such programs can be an effective means to moderating the effects of wood heating in communities susceptible to inversions.

Keywords: air quality, inversions, particulate matter 2.5, woodstove changeout

1. Background

1.1 Wood Heating Patterns

Wood and coal are used as fuel sources by 40% of the world's population for heating and cooking (Carvalho et al., 2016). As the population grows to record numbers, the use of biomass fuels continues to grow as well (Carvalho et al., 2016). With a wide array of health risks associated with these fuel sources (McGowan, Hider, Chacko & Town, 2002; Sanhueza et al., 2009; Boman, Forsberg & Jarvholm, 2003), the World Health Organization (WHO) has deemed wood- and coal-burning to be one of the biggest global environmental health risks (Carvalho et al., 2016; Lim et al., 2012; WHO 2013, 2014) contributing to approximately 3.3 million premature deaths annually (Lelieveld, Evans, Fnais, Giannadaki & Pozzer, 2015).

Wood was the major heating fuel source in the United States (U.S.) until the 1900's when fossil fuel-based heating sources became commonplace and led to a rapid decrease in wood heating after World War II (Cooper, 1980). This lasted until the Energy Crises of the 1970's when high oil and gas prices drove many households to utilize wood heat as a primary or supplementary means of heating their homes (Cooper, 1980). The U.S. federal government as well as state governments supported a residential transition to wood heating since it was a domestic and readily-available resource and therefore seen as a way to promote independence from imported fossil fuels (Cooper, 1980). Similarly, in the 2000's, wood and pellet stoves increased in popularity due to lower costs than oil and gas heat (NHDES, 2010). As a result, over 11 million homes (serving 30 million people) burn wood as either a primary or secondary heating source (U.S. Department of Energy, 2009; Noonan, Ward & Semmens, 2015). The U.S.' shift to residential wood heat raised concerns about the adverse effects on ambient air quality (Cooper, 1980; Sexton, Liu, Hayward & Spengler, 1985). Several studies from the late 1970's and early 1980's found that wood burning was already responsible for significant emissions and associated poor air quality in cities in Maine, Tennessee, Colorado, Vermont and statewide in New Hampshire (Cited in Cooper, 1980: Butcher & Sorenson, 1979; Duncan et al., 1979; Romero, Buchman & Fox, 1978; Dalton et al., 1977; and

Sexton et al., 1985).

1.2 Health Impacts of $PM_{2.5}$

To address local air quality issues in the U.S., the U.S. Environmental Protection Agency (USEPA) adopted the National Ambient Air Quality Standard (NAAQS) in the 1990's that set unacceptable pollution levels (USEPA, 2016b; NHDES, 2010). One such standard relates to the levels of particulate matter that are 2.5 micrometers or smaller (referred to as "particulate matter 2.5" or "$PM_{2.5}$"; USEPA 2016a). $PM_{2.5}$, upon breathing in, is deposited into lung tissue and eventually enters the bloodstream (USEPA, 2016a; Naeher et al, 2007). Wood burning, when air is not dispersed, causes the buildup of $PM_{2.5}$ both within homes with woodstoves and outdoors in a community's local airshed. This exposure can cause airway inflammation, respiratory infections, exacerbation of existing respiratory conditions (such as asthma and chronic pulmonary disease, or COPD) and increased hospitalizations (Naeher et al., 2007; Gan, FitzGerald, Carlsten, Sadatsafavi, & Brauer, 2013; Kocbach Bolling et al., 2009; Sanhueza et al., 2009). Children and elderly populations are the most susceptible to exposure-related ailments (Allen et al., 2008; Koenig et al., 2005; Mishra, 2003; Haley, Talbot & Felton, 2009). Raaschou-Nielsen et al. (2013) found that $PM_{2.5}$ exposure also contributes to lung cancer such that, for every five micrograms per cubic meter ($\mu g/m^3$) increase of $PM_{2.5}$ pollution, the risk of lung cancer increases 18%.

1.3 Conditions for Poor Air Quality in Cold Climate Communities

While $PM_{2.5}$ in many U.S. communities comes from a variety of sources such as power plants and industrial activity (USEPA 2016a), many smaller communities experience higher $PM_{2.5}$ levels as a result of their climate and topography in combination with residential wood burning (Ward & Lange, 2010; Larson et al., 2004; Zheng et al., 2002). In areas with flat topographies or with consistently moderate wind speeds, wood smoke may disperse and air quality effects will not be noticed. For communities situated in valleys in more mountainous or "hilly" topographies, however, air masses are often less able to disperse pollution. This is particularly the case when wind conditions are calm (Spendley & Brehme, 2014; NHDES, 2012). A statewide study by the New Hampshire Department of Environmental Services (NHDES, 2012) reported that, in Keene, New Hampshire, all $PM_{2.5}$ values which exceeded the USEPA NAAQS limit (> 35 $\mu g/m^3$) occurred when winds were below 2 miles per hour (3.22 kilometers per hour). In a separate study, Spendley & Brehme (2014) found $PM_{2.5}$ increases in Keene to be greatest when winds were below 1 mile per hour. When cold, calm conditions are present, colder air can sink to the valley floor and be capped by a slightly warmer air mass above, creating stagnant air conditions that lock in pollutants. This is known as an "inversion" and, when combined with widespread wood burning, commonly results in non-compliance with the USEPA air quality standards for $PM_{2.5}$ (Noonan et al., 2012). Keene, New Hampshire (NHDES 2010, 2012) , Medford, Oregon (Cooper, 1980), Missoula, Montana (Cooper, 1980) and Libby, Montana (Cooper, 1980; Bergauff et al., 2009) are just a handful of many cold climate communities situated in small valleys that frequently experience air quality issues from temperature inversions and wood burning.

1.4 Woodstove Changeout Programs

The age of a woodstove can impact emissions since older stoves tend to emit higher levels of particulates and toxins such as polyaromatic compounds, benzene, aldehydes, carbon monoxide, nitrogen oxides, and respirable particulate matter (Naeher et al., 2007; Noonan et al., 2012; USEPA, 2010). As of 2005, more than 80% of existing woodstoves in the U.S. were older, inefficient models (Clean Air Scientific Advisory Committee, 2005; Noonan et al., 2012). It is estimated that these older stoves emit 15-30 grams of fine particulates per hour (g/h) as compared to those certified by the USEPA which include design features (such as catalytic elements) to operate more efficiently and emit approximately 2-7 g/h (Noonan et al., 2012; USEPA, 2010). To address this, replacing older model woodstoves with newer technology USEPA-certified woodstoves has been utilized as an intervention strategy to help improve air quality in these locations (Noonan et al., 2012). Many governments are now partnering to address the negative impacts of widespread woodstove use through "woodstove changeout" programs which incentivize replacing older woodstoves with USEPA-certified models (Noonan et al., 2012). The first community-wide woodstove changeout took place in Crested Butte, Colorado from 1989-1990 where, of the 406 uncertified stoves in town, nearly 50% were replaced with newer units and another 33% were disabled or removed without replacement (Houck et al., 2005; Ward et al., 2011). Since that time, small-scale woodstove changeout programs have been conducted in Seattle and Spokane, Washington, in Denver, Colorado and in Reno, Nevada as well as in many other communities (Ward, Palmer & Noonan, 2010).

Despite the growing use of woodstove changeout programs to address air quality issues, there is very limited research on their effectiveness. Libby, Montana stands alone as the focus of several studies that assessed the impacts of a woodstove changeout program there. Widespread woodstove use in combination with temperature inversion events have frequently resulted in elevated $PM_{2.5}$ levels in the Greater Libby Valley (Ward et al., 2010) with residential woodstoves contributing 82% of wintertime $PM_{2.5}$ (Bergauff et al., 2009; Noonan et al., 2012; Ward, Rinehard & Lange, 2006;Ward et al., 2010). As a result, Libby often exceeded the 65 $\mu g/m^3$ 24-hour limit set by the 1997 NAAQS and was designated for nonattainment in 2004 (Bergauff et al., 2009; Noonan et al., 2012). Prior to a revised NAAQS in 2006 which set a stronger 24-hour limit at 35 $\mu g/m^3$ (USEPA, 2016b), Libby was the only $PM_{2.5}$ nonattainment area west of the Mississippi River and outside of Southern California (Ward et al., 2010). From 2005-2008, local officials partnered with state and federal agencies as well as with private interests to undertake one of the largest woodstove changeout programs to date in the U.S.; replacing nearly 1200 outdated stoves with new USEPA-certified units (Bergauff et al., 2009; Noonan et al., 2012). In studying the air before and after Libby's changeout program, there was a significant reduction of 20% to 28% in $PM_{2.5}$ levels after the changeout (Bergauff et al., 2009; Ward et al., 2010). With respect to indoor air quality, there was an average drop of 18.5 $\mu g/m^3$ as a result of the changeout, however a subset of homes did not experience any $PM_{2.5}$ reductions whatsoever (Noonan et al., 2012). A study of indoor air quality after a 16-home changeout program on the Nez Perce Reservation also had mixed results (Ward et al, 2011).

Even with varied results regarding indoor air quality, Libby's experience is one indication that a woodstove changeout program can be effective for improving ambient air quality in places with widespread woodstove usage (Ward et al., 2010). Aside from this handful of studies that tend to primarily focus on indoor rather than local air quality, there is not a lot of research on completed woodstove changeout programs and impacts. Considering that there has been significant investment by municipalities, states and the federal government to enact these programs, a lack of understanding regarding their effects is a considerable research gap.

2. Data & Methods

2.1 Study Area: Keene, New Hampshire, USA

This study focuses on the 2009-2010 woodstove changeout program in Keene, New Hampshire, USA. In New Hampshire, vehicular traffic and wood burning for home-heating in winter are the two main sources of $PM_{2.5}$ on the community-wide scale (NHDES, 2012). In Keene, woodstoves are a significant winter heating source and a major contributor to $PM_{2.5}$ pollution (NHDES, 2010; Spendley & Brehme, 2014). Keene sits in a glacial river valley (approx. 12 sq. mi.) surrounded by high hills and is prone to inversion events on calm winter nights (NHDES, 2010, 2012). The use of wood heat during inversions has frequently resulted in $PM_{2.5}$ concentrations exceeding the NAAQS limits for both one-hour and 24-hour basis (NHDES, 2012). Contributing to the problem was the fact that many Keene residents operated woodstoves that were installed before the NAAQS was established in 1997 (NHDES, 2010). Many of these older, uncertified stoves in Keene were estimated to release 40-60 g/h of fine particulates as compared to 2-7 g/h for newer USEPA-certified units (NHDES, 2010).

To address these issues, a unique partnership was established between the New Hampshire Department of Environmental Services (NHDES) and the City of Keene with support and collaboration from the USEPA, the Hearth Patio and Barbeque Association (HPBA), the Southwest Regional Planning Commission, Keene State College, Cheshire Medical Center, New England Wood Pellet, the University of New Hampshire Cooperative Extension and four local woodstove dealers (NHDES, 2010). With funding assistance from the USEPA's Air Program and also with settlement funds from a multi-state lawsuit against American Electric Power, the Keene Woodstove Changeout Program took place from 2009-2010 (NHDES, 2010). The changeout program was a voluntary, incentive-based program seeking to encourage at least 100 owners of inefficient woodstoves to surrender their old units and replace with cleaner burning models by offering \$1,000-\$3,000 rebates for replacements (NHDES, 2010). Additional incentives included tax rebates if installing an Energy Star product or a free ton of wood pellets for those switching to a pellet stove (NHDES, 2010). Through the program, 86 older woodstoves were removed and replaced with 63 newer models, 15 pellet stoves and eight gas appliances (See Figure 1; NHDES, 2010). An additional 11 rebate vouchers had been granted but expired, primarily due to homeowners not willing to cover the additional costs beyond the rebate amount (NHDES, 2010).

Since the changeout program took place, several surveys and monitoring studies have taken place to assess participants' satisfaction with the program as well as to understand how homeowners' heating practices have changed over time (NHDES, 2010; Spendley, Francis, Babcock, Desgroselliers & Grimes, 2013). The USEPA estimated that by changing out nearly 100 older woodstoves that Keene would significantly reduce PM emissions however no studies of air quality have taken place since the changeout was completed (NHDES, 2010). NHDES issued a *Keene Woodstove Changeout Campaign 2009-2010 Final Report* which pointed out, despite the fact that there were no unhealthy air quality days in winter 2009-2010, that air quality and inversions are dependent on weather patterns and it will therefore "be several years before any trends can be identified" (p.9).

This research study seeks to fill this gap by assessing weather patterns and PM emissions for the seven years since the changeout program was completed in order to determine if it was successful or not in achieving $PM_{2.5}$ reductions. In doing so, this study not only provides feedback to the affected stakeholders but also to the larger research community and to policymakers as well. As communities continue to seek ways to address poor air quality, it is imperative to understand if programs targeting older woodstoves are actually an effective means for doing so. This research guides decision-makers at multiple levels of government about whether woodstove changeout programs are a beneficial use of taxpayer dollars for addressing local air quality issues.

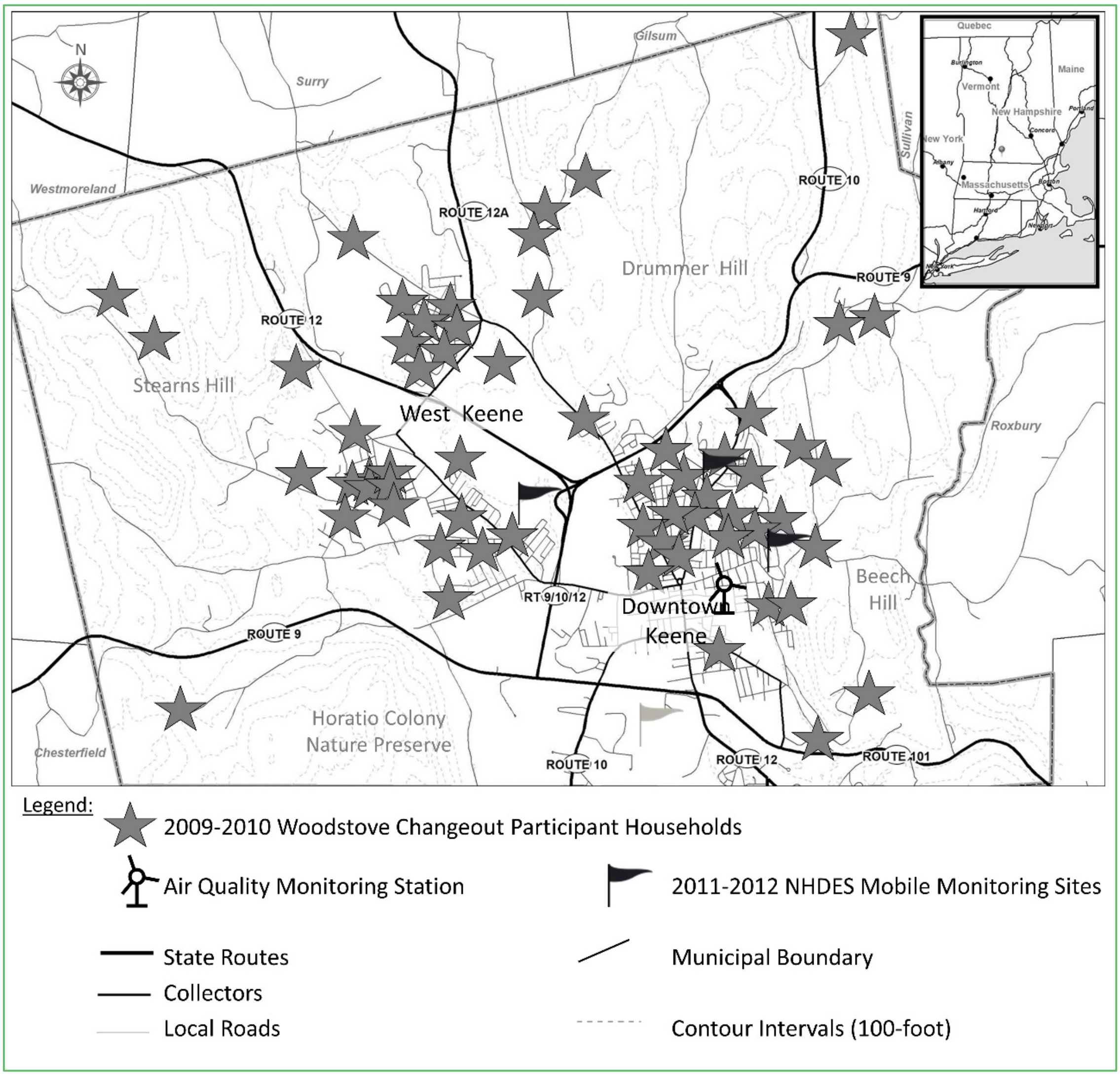

Figure 1. Map of residential woodstove changeout locations in Keene (Created by author with assistance from William Schoefmann and data from NHDES, 2010)

2.2 Air Quality Monitoring

To monitor Keene's air quality, NHDES set up an air quality monitoring station (AQS ID 33-005-0007) in 1989 to track pollutants in the valley (NHDES, 2017). The monitoring station is located on Water Street within the downtown, less than a half-mile from Main Street. The station gathers samples for $PM_{2.5}$ and ozone. $PM_{2.5}$ monitoring began in 1999. The station formerly sampled sulfur dioxide but that ceased after 2004. Monitoring data is available and was accessed through the USEPA website (2018). While the monitoring station is permanently affixed just east of Main Street, its air quality readings appear to be representative of the larger city's air quality conditions. A winter NHDES mobile monitoring study found that four temporary stations set up across Keene reported readings of "surprising uniformity" with the fixed Water Street station (NHDES, 2012). Therefore, while the more geographically-expansive mobile monitoring study was performed in 2011-2012 only, it appears that the historical data from the fixed Water Street site provides an adequate representation of the city's air quality at the larger community scale.

2.3 Data

$PM_{2.5}$ data was the "Daily Mean $PM_{2.5}$ Concentration" as measured in micrograms per cubic meter (µg/m^3; all "local conditions," LC) (USEPA, 2018). From 1999 to 2008, $PM_{2.5}$ measurements were taken approximately every sixth day. From 2009-2017, readings were still taken roughly every sixth day but daily measurements were also taken; resulting in two readings per day every sixth day or so. To analyze comparable data to the 1999-2008 time period, the 6-day readings from 2009-2017 were utilized for comparison and the daily readings for that time period were omitted. In some instances where duplicate measurements were lacking, the daily reading for the sixth day was used as a substitute. For each, the data incorporated was for the winter and therefore included measurements only from December 21st of the prior year to March 20th of the year indicated (e.g. data for the 2000 winter season includes December 21, 1999 to March 20, 2000).

To identify winter nights that were cold and calm, temperature data (in degrees Fahrenheit) from the National Ocean and Atmospheric Administration (NOAA, 2018) were utilized in combination with hourly wind speed data (in miles per hour, or mph) from NHDES (2018). Temperature data provided included the maximum, minimum and observed daily values. For this study, the minimum daily values were utilized to identify the coldest reading for each winter day. For wind speed data, average wind speeds were calculated from 10 pm to 1 am (the average of four readings: 10 pm, 11 pm, midnight and 1 am) on the night before a day with $PM_{2.5}$ recordings and from the four readings from 10 pm to 1 am on the night after a day with $PM_{2.5}$ recordings.

Temperature, wind the night before and wind the night after were all utilized as X-variables in separate linear regression models with $PM_{2.5}$ as the Y-variable. All three were significantly and negatively correlated with $PM_{2.5}$ (P-value <0.05) however only wind speed during the night before had anything close to a moderate explanatory value (R-square 0.27) while the other two variables had R-squares values of 0.04 or less. This shows that there is a significantly stronger connection between wind speeds than temperature in the buildup of particulate matter during the winter months and that lower wind speeds during the night relate to higher $PM_{2.5}$ readings on the ensuing day. As a result, wind speed during the night before was utilized in applicable models. For example, on January 19, 2000, the minimum temperature was -8 F, the $PM_{2.5}$ was 14 µ/m^3, and the wind speed included was 0.75-mph (the average speed from 10 pm on January 18, 2000 to 1 am on January 19, 2000).

2.4 Methods

To compare conditions before and after Keene's woodstove changeout, data from 2000-2008 were compared to data from 2011-2017. Where wind speed data was missing for dates of $PM_{2.5}$ samples, those dates were removed from the analysis. Due to large gaps in wind speed data for winter months in 2001 and 2003, those years were omitted from these analyses. Therefore the 2000-2008 time period includes data for: 2000, 2002 and 2004-2008. In total, six t-Tests were performed testing the hypotheses that samples from Population A and Population B were from the same population and therefore equal with no significant differences between them.

3. Results

3.1 Overall Winter $PM_{2.5}$ Levels

In comparing winter particulate matter levels in the years prior to the woodstove changeout to those after the changeout program was completed, a significant reduction in $PM_{2.5}$ was experienced in Keene (See Tables 1 & 2). Prior to the changeout, the average observed $PM_{2.5}$ was 15.60 µg/m^3. After the changeout program was completed, the average $PM_{2.5}$ was 11.10 µg/m^3 (a mean reduction of 4.50 µg/m^3). The two time periods were statistically different from each other. Specifically, in the time period following the changeout, $PM_{2.5}$ levels were 15% to 43% (2.33 to 6.67 µg/m^3) lower than in the "before" time period.

3.2 Temperature & Wind

To assess if the significant reduction in wintertime $PM_{2.5}$ is somehow related to weather factors, temperature and wind speed readings in the before- and after-changeout time periods were compared. For temperature, the mean temperature from 2000-2008 (2001 and 2003 omitted) was 11.47 degrees Fahrenheit while the mean temperature for 2011-2017 was 13.31 degrees Fahrenheit. Despite being an average 1.84 degrees higher during the more recent time period, these periods were not significantly different from each other and therefore not expected to have a significant impact on wood burning for home heat and associated particulate matter pollution.

Table 1. Descriptive statistics

	Overall Winter $PM_{2.5}$		Low Daily Temperature (in degrees Fahrenheit)		Wind Speed (in mph; night before)		$PM_{2.5}$ after Calm Nights (Wind <= 2 mph)		$PM_{2.5}$ after Windy Nights (Wind > 2 mph)	
	2000-2008*	2011-2017	2000-2008*	2011-2017	2000-2008*	2011-2017	2000-2008*	2011-2017	2000-2008*	2011-2017
Count	102	102	102	102	102	102	68	55	34	47
Mean	15.60	11.10	11.47	13.31	1.76	3.00	18.38	14.09	10.04	7.61
Median	14.60	9.70	11.00	15.00	1.00	1.60	17.20	11.70	9.00	7.40
Mode	11.90	11.10	14.00	17.00	0.00	0.60	11.90	11.30	5.20	8.30
Min.	3.80	2.40	-13.00	-13.00	0.00	0.30	3.80	4.20	4.80	2.40
Max.	43.40	61.50	35.00	36.00	9.00	11.60	43.40	61.50	25.40	22.30
Range	39.60	59.10	48.00	49.00	9.00	11.30	39.60	57.30	20.60	19.90
Std. Dev.	7.93	7.79	11.91	12.55	1.87	2.74	7.86	8.97	4.35	3.96
Var.	62.80	60.71	141.84	157.54	3.51	7.53	61.84	80.52	18.91	15.67

* 2001 and 2003 omitted due to data gaps

Table 2. T-test results

	Overall Winter $PM_{2.5}$	Low Daily Temperature (in degrees Fahrenheit)	Wind Speed (in mph; night before)	$PM_{2.5}$ for 2000-2008*	$PM_{2.5}$ for 2011-2017	$PM_{2.5}$ after Calm Nights
t-Test Pop. A:	2000-2008*	2000-2008*	2000-2008*	<= 2 mph	<= 2 mph	2000-2008*
t-Test Pop. B:	2011-2017	2011-2017	2011-2017	> 2 mph	> 2 mph	2011-2017
Mean Difference	4.50	-1.84	-1.24	8.34	6.48	4.29
t Stat	4.09	1.08	3.77	5.75	4.58	2.82
Two-tail P-value	0.00	0.28	0.00	0.00	0.00	0.01
Lower CI	2.33	(not sig.)	-1.89	5.46	3.67	1.28
Upper CI	6.67	(not sig.)	-0.59	11.22	9.29	7.30

* 2001 and 2003 omitted due to data gaps; CI= Confidence Interval

The average wind speed during 2000-2008 was 1.76-mph while the average for the 2011-2017 time period was 3.00-mph. The two time periods are significantly different from each other with the more recent time period having winds that are 0.59- to 1.89-mph higher (mean 1.24-mph higher). Since there was a moderate relationship between wind speed on the night before and $PM_{2.5}$ readings (see Section 2.3), the significantly higher wind in the recent time period most likely has had at least some impact on dispersing pollutants and lower $PM_{2.5}$ levels as a result. As wind speeds 2-mph or less were identified by NHDES (2012) as a threshold in Keene for pollutants to exceed 35 μg/m^3, it is notable that the average wind speed in the earlier time period was below 2-mph while in average for the recent time period is above this threshold and supports the notion that wind speeds could be having at least some impact in dispersing pollutants.

3.3 Wind & $PM_{2.5}$ Levels

Using the 2-mph threshold as a breakpoint within each time period, the average $PM_{2.5}$ during 2000-2008 when winds were 2-mph or less was 18.38 μg/m^3 while the average when the winds were faster than 2-mph was 10.04 μg/m^3 (significantly different from each other with a mean difference of 8.34 μg/m^3). Similarly, there was a significant difference in $PM_{2.5}$ levels in the 2011-2017 time period when comparing calm (14.09 µg/m^3 when winds are 2-mph or less) and windier conditions (7.61 µg/m^3 when winds are over 2-mph). It is notable that the average $PM_{2.5}$ levels are lower in the recent time period for both the calm and winder conditions; suggesting that the changeout has had at least some effect.

3.4 $PM_{2.5}$ Levels on Calm Winter Nights

While significantly higher wind speeds may be impacting $PM_{2.5}$ levels, the woodstove changeout was enacted to address air quality issues resulting from inversion events. As inversions occur on calm winter nights, the $PM_{2.5}$ levels for days after a calm night (average winds 2-mph or less) were compared as well. Prior the woodstove changeout program, the average $PM_{2.5}$ after calm nights was 18.38 µg/m^3. After the changeout was completed, the average $PM_{2.5}$ was 14.09 µg/m^3 (a mean reduction of 4.29 µg/m^3). The two time periods were significantly different from each other with the time period after the changeout having $PM_{2.5}$ levels that were 7% to 52% (1.28 to 7.30 µg/m^3) lower than in the "before" time period.

3.5 Summary

Wintertime $PM_{2.5}$ pollution in Keene has decreased significantly in the time period following the woodstove changeout program (a mean reduction of 4.50 µg/m^3). Since poor air quality often results from inversion events in cold climates, the buildup of particulate matter locally is weather dependent. It was found that $PM_{2.5}$ was moderately correlated with wind speeds on winter nights (R-square value of 0.27). In the time period since the changeout took place, nighttime wind speeds (3.00-mph) were significantly higher as compared to the earlier time period (1.76-mph) and therefore could be a factor in the significant drop in $PM_{2.5}$. This does not negate the value of the changeout program as $PM_{2.5}$ after calm nights (when winds are not dispersing pollution) was significantly reduced by 7% to 52% (for a mean decrease of 4.29 µg/m^3; from 18.38 µg/m^3 prior to the changeout program to 14.09 µg/m^3 after). Therefore, it appears that the woodstove changeout program has served to significantly reduce $PM_{2.5}$ on the dates when poor air quality conditions are most likely to occur.

4. Conclusion

As the world population grows, so too does the use of biomass fuels for heating and cooking (Carvalho et al., 2016). Aware of these risks, many governments in the U.S. are taking steps to improve air quality and one way that has become popular is through woodstove changeout programs. Despite the widespread utilization of such programs, very little has been done to study and understand the impacts of changeout programs after their completion. This research assessed the woodstove changeout program in Keene, New Hampshire; a community prone to poor air quality during inversions on calm winter nights. With a goal of improving air quality during inversion events, the changeout successfully reduced $PM_{2.5}$ on calm winter nights by an average of 23%. This finding echoes the 20% to 28% reduction experienced in the larger Libby, Montana valley through their changeout program (Bergauff et al., 2009; Noonan et al., 2012; Ward et al., 2010). The experiences in both Keene and Libby suggest that woodstove changeout programs can be an effective way to reduce $PM_{2.5}$ in places with widespread woodstove use and prone to wintertime inversion events. It also suggests that, like in Libby, a woodstove changeout program will only go so far to reduce $PM_{2.5}$ levels and that additional improvement may require transitioning away from wood heating altogether (Ward et al., 2010). With that in mind, new changeout programs should consider higher incentives for homeowners to transition entirely away from wood heating in these communities. As the use of wood fuel is probably based on a variety of household preferences and conditions, additional study is needed to assess the willingness by households to transition away from wood burning as their home heating source.

The impacts of climate change may not be felt equally across different geographies. While Keene's higher wind speeds have served to improve local air quality to some degree, some communities may experience the opposite transition towards calmer conditions and a higher buildup of $PM_{2.5}$ with the associated poor air quality. Policy-makers at all levels should think strategically about how to address air quality issues comprehensively. In situations as in Keene and Libby, woodstove changeout programs appear to be a successful step to get communities more in compliance with USEPA standards during winter inversions. Elevated $PM_{2.5}$ levels that put a community close to the standard on a normal basis, however, need to be addressed as a root cause as well. Automobiles, through emissions, braking and tire wear, are a major source of $PM_{2.5}$ (USEPA, 2016; Wahlström, Olander & Olofsson, 2010; Panko, Chu, Kreider & Unice, 2013). As such, transportation systems and urban development patterns present many opportunities to proactively address a major contributor of $PM_{2.5}$ pollution in the developed world. Whenever large-scale efforts (whether woodstove changeouts or otherwise) are enacted to improve air quality, follow-up studies such as this one should be performed to assess the success of each effort. Doing so will allow for continual advancements in how we effectively improve environmental conditions, reduce health risks and enhance the overall livability of our communities.

Acknowledgements

The author would like to thank Michael Little, Kendall Perkins and Patricia North of the New Hampshire Department of Environmental Services for their assistance with weather data as well as Rhett Lamb and William Schoefmann of the City of Keene Planning Department for their assistance at all stages of the project.

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