Behaviour wedge profiles for cities

Karen Ehrhardt-Martinez
Human Dimensions Research Associates
6380 Bluebird Court
Niwot, CO 80503
United States of America
KEhrhardt@HumanDimensionsResearch.org

Keywords
behaviour, energy conservation, energy efficiency programmes, local activities, achievable savings estimates

Abstract
A growing body of research has provided clear evidence of the large scale, energy and carbon reductions that could be achieved by shifting household practices and technology choices. Estimates of achievable savings have ranged from 20 to 30 percent in the short- to medium-term in the residential and personal transportation sectors alone. In the United States, the savings from such interventions would reduce total national energy consumption by roughly 9 % and cut carbon emissions by 7.4 %. Such estimates have caught the interest of a large number of U.S. cities who are actively engaged in developing and implementing climate action plans and who are eager to find additional mechanisms for reducing energy consumption. Despite their interest, the cities have found national-level data to be insufficient for tackling local energy challenges. While national-level findings are useful, they are unable to identify city-specific opportunities that take unique, local factors into account, such as local climatic conditions, the characteristics of the local building stock, technology saturation, technology use patterns, and the lifestyles, attitudes and preferences of local populations. Such limitations have left cities to find their own means of determining which behaviours offer the largest savings opportunities; information that would help cities be more strategic in their development of behavioural programs. While some cities have opted to spend hundreds of thousands of dollars to collect their own data, most do not have the budgets to fund costly data collection or analysis efforts. In response to these challenges, we have been working with the Urban Sustainability Director's Network (USDN) and five cities to develop a low-cost approach to estimate the scale of city-specific savings opportunities and to document the sets of behaviours that are likely to result in the most savings in particular cities given the unique characteristics of the local climate, built environment, lifestyles and behaviours. This presentation will 1) outline the core components of the behaviour wedge profile assessment methodology, 2) present estimates for five specific U.S. cities, and 3) discuss how cities are using this information to more strategically target their programs and policies in ways that maximize behaviour-related energy and carbon savings.

Introduction
Since 2008, a growing body of research has begun to explore the range of energy and carbon savings that might be achieved in the United States through policies and interventions that focus on shifting the energy use practices and technology choices of the nation's 115 million households (Gardner and Stern 2008, Laitner et al. 2009, Dietz et al. 2009, and NRDC and Garrison Institute 2010). In general, these studies suggest that current levels of energy consumption and carbon emissions from the household and personal transportation sectors alone could be reduced by an estimated 20–30 % in the short to medium-term (<10 years) through efforts that influence the everyday practices and purchasing decisions of households. Such savings could reduce national level carbon emissions by 7.5 to 14 percent and reduce energy consumption by an estimated 9 percent. The following paragraphs provide a brief summary of the findings from these studies.

According to Gardner and Stern (2008), U.S. households currently account for about 38 percent of national carbon emissions – just through their direct actions alone. Notably, this amount of emissions is large – "greater than that of any entire country except China and larger than the entire U.S. industrial sector" (Gardner and Stern 2008: p. 13). The potential energy and carbon savings associated with household actions were also found to be large. In fact, the study concluded that the strategic engagement of U.S. households in energy conservation and energy efficiency could reduce sector emissions by nearly 30 percent and national carbon emissions by as much as 11 percent. These findings are particularly important because such savings could be achieved without the need for the development of any new technologies, making any major economic sacrifices, or reducing households' sense of well-being.

This savings opportunity is not new but it has remained unrealized for several important reasons. Foremost among these, households lack accurate, accessible, and actionable information on how best to achieve potential savings through their own actions. Overcoming this barrier requires that households know not only what they can do but which actions will produce the most benefits (Jaffe and Stavins 1994). Gardner and Stern's study points to evidence that although many householders are motivated, they lack the necessary knowledge to act and – in the face of long and indiscriminate lists of actions that they can take – they often make choices based on mistaken notions about which actions are most beneficial.

According to the authors:

> When strategies are proposed for households, they often appear in laundry list format, giving little or no priority to effectiveness. It is easy for households that want to cope with rising gasoline prices and heating and cooling bills to respond by taking small actions under the impression they are saving energy, while they are actually making a negligible dent in their personal energy consumption (p. 14).

Similarly, estimates of potential savings made by householders often diverge dramatically from similar estimates made by energy experts (sometimes by a factor of four). In general, householders have been found to emphasize highly visible actions that can reduce energy use if repeated regularly, such as lowering winter thermostat settings and turning off lights, and they overestimate the potential energy savings from these actions. Meanwhile the savings from many actions with higher energy-saving potential but low visibility (such as installing storm windows) were underestimated.

Gardner and Stern conclude that "the public needs more direct and coherent advice concerning household and individual actions" (2008: p. 15) Instead of providing long and unranked lists – as many books and articles on the subject typically do – the authors suggest: "it is much more effective to focus campaigns on a very small number of specific actions that can make a real difference and disseminate the message repeatedly through multiple media outlets, using sources that are credible to target audiences" (2008: p. 16). Timing is also important. When possible, information should be provided when audience members are poised to make choices about the issue the message addresses (for example, in public health, in the doctor's office or at the cigarette counter). *A necessary first step is to identify which actions are the most effective.* By identifying the most promising opportunities, programs can be more targeted and have a greater impact.

Given the significant level of savings identified by Gardner and Stern, it is notable that the assessment is based on an evaluation of only 27 specific actions in the household and personal transportation sectors. Of these actions, the authors categorize 13 as curtailment types of behaviours in which people are required to cut back on certain activities. The remaining 14 actions are categorized as *efficiency* behaviours which they characterize as choices to invest "in home equipment that lowers energy costs without sacrificing desired energy services."

Several subsequent studies (Laitner et al. 2009, Dietz et al. 2009, and NRDC and Garrison Institute 2010) have performed similar assessments of the energy and carbon emissions savings opportunities associated with household energy use and personal transportation practices and decisions in the United States. These studies have come to similar conclusions. For example, in 2009 Laitner et al. assessed the amount of *energy* (as opposed to carbon) that could be saved by households. This study explored a list of roughly 120 behaviours associated with household energy use and personal transportation practices. Similar to Gardner and Stern (2008), Laitner and his team of researchers concluded that current levels of energy use in the residential and personal transportation sectors could be reduced by an estimated 20–25 percent in the short-term (5–8 years), representing a reduction of 9 percent of total U.S. energy consumption with the majority of the savings resulting from a relatively short list of behaviours. In this case, the savings estimates were formulated to reflect the "realistically achievable savings" as opposed to the entire savings opportunity assuming a best case scenario. Findings indicate that the largest opportunities are associated with refrigeration, air conditioning, lighting, space heating and personal transportation, while additional savings opportunities are associated with hot water heating, consumer appliances and other miscellaneous end uses. Notably, 57 percent of the estimated savings resulted from low-cost and no-cost types of behaviours while 43 percent were associated with household investments in insulation, appliances and HVAC equipment.

During the same year, Dietz et al. (2009) considered the potential *carbon* savings from a list of just 33 actions representing 17 household action types in 5 behaviourally distinct categories. Their estimates used a similar methodology as Laitner et al. (2009) with the goal of estimating the "reasonably achievable emissions reductions (RAER)." Their findings suggest achievable *carbon* savings of 20 % in the household sector within 10 years if the most effective non-regulatory interventions are used. Findings from this study suggests that the largest savings are likely to be associated with ten household action types – half of these are associated with investment-type activities while the other half are strictly associated with conservation decisions and practices.

These studies have laid the groundwork needed to quantify the savings opportunities associated with everyday choices and practices and to recognize the impact that they could have on energy consumption and carbon emissions at the national level in the United States. They also provide an effective framework for assessing the scale of the behavioural opportunities that abound in the United States and in other countries with similar lifestyles and practices. Where theses studies fall short, however, is in their inability to account for important sources of variation across regions, states, and cities.

The need for city-specific behavioural profiles

As progress on national climate policy continues to be deadlocked in the United States, cities have emerged on the forefront of efforts to address energy and climate change challenges (Lacy 2014,Adler 2014, Hower 2014). As part of their efforts, cities are increasingly recognizing the importance of engaging with urban residents using people-centered approaches that help households move away from wasteful energy use practices, reduce energy consumption, and lower carbon emissions (Ehrhardt-Martinez 2012). These approaches are appealing on many levels. When compared to more traditional technology-focused efforts, emerging research (as summarized above) suggests that people-centered initiatives – focused on the decisions and practices of people and households – can achieve significant, short-term reductions in energy demand and that much of the energy saving could be achieved with relatively limited investments in new techologies. Given their focus on energy practices and decision making, such efforts are also more likely to help households and cities to transition away from a culture of energy waste and toward a culture of more sustainable use.

The current roadblock for cities lies in the mismatch between national-level research and city-level sustainability initiatives. While national-level research provides compelling evidence for aggregate, national-level savings opportunities, it is unable to translate those findings into insights that are actionable at the city level. More specifically, national-level estimates fail to account for area-to-area variation in a wide range of important variables such as climate characteristics, building infrastructure, technology saturation and technology use patterns. Without more specialized information, cities (and states) lack the ability to effectively develop and justify behaviourally-focused policies and programs at city and state levels.

What cities need are quantifiable estimates of the scale of potential savings for *their* particular city and clear information concerning the sets of behaviours that promise the largest savings opportunities given *their* city's unique characteristics. Such information is vital to city sustainability efforts because it provides cities with the means to:

- Evaluate the relative importance of behavioural initiatives as part of a larger, city-wide sustainability, climate, and/or energy initiative,
- Prioritize investments in different types of projects and programs and focus limited resources on a more precise and promising set of interventions,
- Write more effective funding proposals, and
- Develop more targeted marketing and communications efforts.

In sum, the efforts of cities to enhance local sustainability efforts would benefit greatly from city-specific information about behavioural opportunities that recognizes local conditions and enhances the likelihood of effectively engaging city residents. Not surprisingly, however, this type of information is expensive to develop because it typically requires cities to engage in primary data collection efforts and data analysis. In response, a small group of cities decided to pursue a joint effort that would explore potential means of using *existing* data sources to develop low-cost, city-level estimates of behavioural opportunities for reducing energy demand and carbon emissions. The goal was to develop an estimation model that would use existing data from a variety of sources to arrive at reliable measures of *achievable* savings. The results of the analysis would be captured in a city-level Behaviour Wedge Profile report, giving cities a foundation of information upon which they could be more strategic in their development of behavioural programs.

Core components of the municipal behaviour wedge profile methodology

Estimates created using the Municipal Behaviour Wedge approach rely on the use of existing data sources to develop low-cost, city-specific estimates of *achievable* energy savings in the realms of residential and commercial buildings. This paper focuses exclusively on the development of the set of *residential sector* estimates associated with the decisions and actions of individuals and households. Such estimates are provided for two periods of time, including a set of short-term estimates (4 years or less) and a set of medium term estimates (8 years or less).[1] The Residential Sector Behaviour Wedge Report also specifies a separate set of estimates for single-family and multi-family homes. Similar to prior, national-level behaviour wedge studies, Municipal Behaviour Wedge Profile estimates represent conservative measures of the true range of potential energy/carbon savings that could be achieved through shifts in behaviours, practices and choices. The estimates are considered to be conservative for at least four reasons: 1) the estimation methodology includes only a small, albeit thoughtfully selected, subset of the long list of practices that could result in energy savings, 2) final estimates of ciy-wide savings associated with any given behaviour take into consideration measures of household eligibility and are calculated only for the set of households who are found to be eligible to take a particular action, 3) city-wide savings estimates for eligible households are further constrained by adjusting for likely participation rates (multiplying the estimated savings for eligible households by estimated rates of participation), and 4) savings estimates for behaviours that require regular and repeated performance also include estimates of compliance rates. Unlike some of the prior studies discussed above, the Municipal Behaviour Wedge Model does not include estimates of energy savings associated with shifts in personal transportation behaviours.

The choice to focus on a subset of behaviours was made to consciously highlight those behaviours that offer the greatest savings opportunities. As noted by Gardner and Stern above, the presentation of laundry lists of actions is rarely helpful and can often be overwhelming and even counterproductive. Given the more than 200 behaviours associated with residential energy consumption, we chose to narrow our focus to those that were likely to prove most beneficial. The development of the Behaviour Wedge profile was therefore strategically constructed with a focus on a limited range of behaviour-based savings opportunities. The identification of the most relevant behavioural opportunities was informed by previous research (Gardners and Stern 2008, Laitner et al. 2009, Dietz et al. 2009) and in-

1. These time periods were selected by the cities and correspond to city planning cycles.

formation pertaining to the *size of potential* savings, household eligibility, and the likelihood of adoption. As a result, while the estimated energy savings presented in the Behavior Wedge Profile represent only a slice of the larger universe of potential behaviour-related energy savings, they are likely to result in a disproportionately large share of potential savings. Profile estimates are also moderated by critically assessing the proportion of households that are eligible to participate in any particular behaviour as well as their likelihood of participation. For example, households that don't have clothes washers are not eligible to reduce energy consumption through reduced use or changes in clothes washer settings. Similarly, households that don't have central air conditioning are not eligible to reduce AC-related demand through the use of programmable thermostats. Estimates of eligibility were derived from state and regional data on household characteristics, technology saturation and use patterns of household technologies provided by the Residential Energy Consumption Survey (RECS) – a periodic survey performed by the U.S. Energy Information Administration (EIA). Such estimates are further moderated by estimating the *likelihood of participation* as determined through a review of the literature as well as from feedback from a panel of utility industry experts who drew from their own program implementation and evaluation experience to review and assess our preliminary set of literature-based estimates of participation rates. Looking across the range of behaviours included in the model, participation rates range from a low of 10 % to a high of 35 % in the short-term among eligible households. In the medium-term, participation rates range from 20 % to 50 % with the exception of ceiling fan use and use of CFLs which have estimated participation rates of 60 %.

Figure 1 provides a graphic summary of the variety of data sources that are used in the behaviour wedge estimation model, including data from the U.S. Census Bureau, the Residential Energy Consumption Survey (RECS), and insights from industry experts and related literature. RECS data provide the core set of data for the Behaviour Wedge estimates. The RECS data set includes detailed information about housing characteristics, technology saturation, technology use patterns and energy consumption for 16 U.S. states and a variety of state clusters. These data play an important role is establishing estimates of baseline energy use and assessing the proportion of households that should be considered eligible to save energy through a particular shift in behaviour. The U.S. Census provides city-specific information about the characteristics of the local housing stock, local demographic information, and economic and poverty measures. These data are important for understanding the local context and adjusting RECS data to reflect city-level characteristics. Expert insights and relevant literature are use to assess likely household participation rates, compliance rates, and the likely range of savings associated with particular behaviours. Taken together, all three sources of data provide the means for estimating both existing patterns of energy consumption and potential savings opportunities.

Using the data sources identified in Figure 1 as data inputs, the Behaviour Wedge model relies on a set of algorithms to calculate estimates of achievable energy savings for a set of 32 specific behaviour-related measures. The behaviours that are represented were selected in an effort to develop a relatively short list of those behaviour-related measures that are likely to represent the largest achievable savings opportunities. The effort began with a much longer set of behaviour-related measures which was subsequently honed to a shorter list based on earlier estimates of energy savings associated with each (see Laitner et al 2009 for more information concerning the full list of behaviour-related measures that were considered in the development of this model.) The selected measures are identified in Table 1.

For each of the behaviours listed above, four distinct algorithms are used to estimate end-of-period annual energy savings for each of two time periods and two types of housing structures. Achievable *short-term* savings (achievable in 4 years or less) and achievable *medium-term* savings (achievable in 8 years or less) are estimated separately for *single-family* homes and for *multi-family* homes and rely on different assumptions concerning program participation.

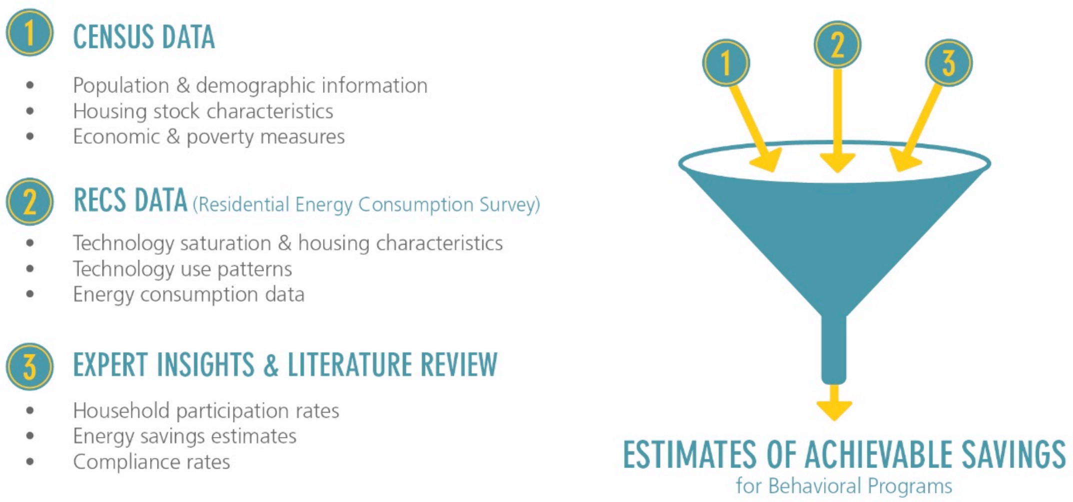

Figure 1. Data sources and inputs for the municipal behaviour wedge model.

Table 1. Behaviours Included in the municipal behaviour wedge model.

	Behaviour-Related Measures	Change in Practice	Energy Stocktaking	Purchasing/Investment Decision
1	Accelerated heating equipment replacement: Enhance the rate at which households replace old heating equipment.			x
2	Heating equipment maintenance: Increase the proportion of households who service and maintain their heating equipment to maximize energy efficiency.		x	
3	Setback of heating thermostat: Increase the proportion of households using EPA-recommended settings.	x		
4	Use of programmable thermostat for heating: Increase the proportion of households with programmable thermostats who use them and who use EPA-recommended settings.		x	
5	Heating-related weatherization: Increase the proportion of households who have weatherized their homes.		x	
6	Heat conservation actions (closing doors and vents): Increase the proportion of households who close doors and vents to unused rooms.		x	
7	Window insulation: Increase the proportion of households with single-pane windows who use storm windows or other forms of window insulation.		x	
8	Accelerated cooling equipment replacement: Enhance the rate at which households replace old cooling equipment.			x
9	Cooling equipment maintenance: Increase the proportion of households who service and maintain their AC equipment to maximize energy efficiency.		x	
10	Setback of cooling thermostat: Increase the proportion of households using EPA-recommended settings.	x		
11	Use of programmable thermostat for AC: Increase the proportion of households with programmable thermostats who use them and who use EPA-recommended settings.		x	
12	Use of ceiling fans instead of AC: Increase the use of existing ceiling fans as an alternative to AC and as a means of increasing thermostat settings and increase the proportion of households with ceiling fans.	x		
13	Cooling-related weatherization: Increase the proportion of househols who have weatherized their homes.		x	
14	Cooling conservation actions (close vents and doors)Increase the proportion of households with AC who close doors and vents to unused rooms.		x	
15	Use of blinds, etc to reduce solar heat gain: Increase the proportion of households who use blinds, shades, and window film to reduce solar heat gain and AC demand.	x		
16	Discard/unplug second refrigerator/freezer: Reduce the proportion of households who have a second refrigerator or stand alone freezer in their garage or basement.		x	
17	Lower water heater settings: Increase the proportion of households who have their water heaters set according to EPA guidelines.		x	
18	Add water heater insulation: Increase the proportion of households who use insulation on old water heaters.		x	

The table continues on next page. →

Table 1. Continuation.

	Behaviour-Related Measures	Change in Practice	Energy Stocktaking	Purchasing/Investment Decision
19	Purchasing an energy efficient clothes washer: Accelerate the replacement of old clothes washers with energy efficient models.			x
20	Using cold water and efficient settings on washers: Increase the proportion of households who regularly use cold water and energy efficient settings on their washing machines.	x		
21	Reduce laundry loads: Reduce hot water consumption by reducing the average number of weekly loads of laundry.	x		
22	Air drying laundry: Reduce clothes dryer energy consumption by increasing the proportion of laundry that is air dried.	x		
23	Replacing desktop computers with laptops: Increase the proportion of households who use more energy efficient laptop computers rather than desktop computers.			x
24	Managing vampire loads: Increase the proportion of households who use smart strips on home entertainment and home office systems.	x		
25	Managing plug loads: Increase the proportion of households turn off TVs, video games, printers, and other equipment when not in use.	x		
26	Installing CFLs: Increase the proportion of households and the proportion of sockets with CFLs or other efficient bulbs.		x	
27	Turn off unused indoor lighting: Reduce the proportion of lights that are left on when nobody is in the room.	x		
28	Turn off unused outdoor lighting: Reduce the proportion of households who leave outdoor lighting on all night.	x		
29	Accelerate replacement of inefficient pool pumps: Increase the rate of adoption of more energy efficient pool pumps.			x
30	Change pool pump settings: Increase the proportion of households using pool pump timers effectively.		x	
31	Add/use pool covers: Increase the proportion of households who use pool covers to maintain water temperatures.	x		
32	Install/use hot tub timers: Increase the proportion of households who use hottub timers to reduce the number of heating hours.		x	
	TOTAL	12	15	5

Each of the sample equations show in Table 2 specifies the number of homes that fit the category in question (single-family or multi-family), the percentage of homes that are eligible to "participate" in the behaviour in question, an estimate of likely participation rates, and an estimated level of savings per household for the behaviour in question.

Census data were used to provide accurate measures of the number and types of homes in each city. As noted earlier in this paper, household eligibility measures were determined based on behaviour-relevant information gleaned from the RECS data set. For example in order to determine the proportion of households that were eligible to unplug or dispose of a second refrigerator, the model draws from state (or state cluster)-specific data from RECS that measure the proportion of households with two or more refrigerators. Likely short-term and long-term participation rates were estimated using a two-step approach. First, a literature review was performed to assess historical participation rates associated with a range of utility programs and and non-utility based programs (See Latiner et al. 2009 for more information). Second the data collected from the literature review were presented to a set of eight behavioural- and utility program experts who provided comments and suggestions to

Table 2. Algorithm components.

		Savings Period	
Housing Type		Short-Term	Medium-Term
	Single Family (SF)	(Number of Homes) x (% single family) x (% SF eligibility) x (likely short-term SF participation) x (current SF energy use) x (estimated savings rate per HH)	(Number of Homes) x (% single family) x (% SF eligibility) x (likely medium-term SF participation) x (current SF energy use) x (estimated savings per HH)
	Multi-Family (MF)	(Number of Homes) x (% multi family) x (% MF eligibility) x (likely short-term MF participation) x (current MF energy use) x (estimated savings per HH)	(Number of Homes) x (% multi family) x (% MF eligibility) x (likely medium-term MF participation) x (current MF energy use) x (estimated savings per HH)

Table 3. Heating Equipment for Urban Households within the Maryland state cluster as applied to households in the City of Baltimore, Maryland.

Heating	Urban Single-Family Households		Urban Multi-Family Households	
Central Heating System (yes)	174,934	87.5 %	76,913	79.9 %
No Regular Heating System Maintenance	79,700	39.9 %	48,987	50.9 %
Age of heating equipment (15+ year)	68,033	34.0 %	27,110	28.2 %

help further refine the likely rate of household participation for particular behaviours and within specific time periods. Estimates of average energy savings rates were collected from a wide range of documents including the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) as well as a wide range of utility-sponsored materials.

Data selection and variable development

As noted above, relevant variables relating to infrastructure, housing characteristics, technology saturation and technology use were identified and pulled from the RECS micro data for the geographical area in question to create a location-specific data set. These data were used to assess the proportion of households living in certain types of housing, determine which types of households had access to different types of technologies, and to assess patterns of variation in household technology use. Such assessments also considered how such patterns varied for urban versus non-urban households and for single-family versus multi-family households.

For example, in order to understand the achievable savings opportunities of a heating-related behaviour like the accelerated replacement of a household's central heating equipment, it is important to know the current proportion of households that have central heating and the age of the heating equipment. Knowing the equipment's age is one means of determining household eligibility and can also provide some insights concerning the likelihood of accelerated adoption as well as a broader understanding of the likely efficiency levels of existing technology (and therefore the potential efficiency gains). The following table provides some examples of several heating-related variables that were assessed in the development of the Behaviour Wedge Energy Savings estimation model for Baltimore. The data presented in Table 3 reveals that – among urban households in the Maryland state cluster – roughly 87 percent of urban single-family households and 80 percent of urban multi-family households had central heating systems. Roughly 40 percent of urban single-family households failed to perform regular maintenance on their heating systems and roughly 51 percent of urban multi-family households failed to perform regular maintenance. Finally about one-third of urban single family households had heating equipment that was more than 15 years old, while the equivalent proportion for urban multi-family households was 28 percent.

INTEGRATING CENSUS DATA TO REFLECT LOCAL HOUSING CHARACTERISTICS

Since RECS data are not collected at the city level, Census data were used to weight the RECS data with the goal of making it more representative of the type of housing found at the city level.

To use Baltimore as an example, we were particularly interested in the comparative age and size of the housing stock for the City of Baltimore as compared to urban Maryland more generally. A comparison revealed important distinctions. As can be seen in Table 4, the housing stock in Baltimore tends to be both older and smaller than that for urban areas in Maryland as a whole. Census data indicate that while roughly 29 percent of urban Maryland homes were built before 1950, the comparable proportion of homes in Baltimore is 55.4 percent. And, whereas roughly 33 percent of homes in urban Maryland were built between 1980 and 2000, the comparable number for Baltimore was a much smaller 8 percent. Given these differences in the average age of the housing stock, it isn't surprising that the average home size in Baltimore is also smaller than the average urban home within the larger state cluster. As shown in the table, the average home in Baltimore is roughly 1,280 square feet compared to the average home size in urban Maryland of roughly 1,650 square feet.

In order to better represent the specific housing characteristics found in the City of Baltimore, RECS data for the Maryland state cluster were reweighted to reflect the distribution of housing by age and type in the City of Baltimore. The reweighted data set served as the basis for subsequent assessments of behaviour-related energy savings opportunities.

Once the RECS data were reweighted, they were plugged into the specified algorithms for each of the behavioural measures to create a set of savings estimates. These estimates were then scaled to the specific number of households in the City of Baltimore. In addtion to the estimates of behaviour-related energy savings opportunities, the Municipal Behaviour Wedge Profile reports also provide some relevant contextual information aimed at helping cities to evaluate how their unique context might create both, city-specific opportunities and constraints as compared to conditions throughout the larger state context. Table 5 highlights a select set of statistics for the City of Baltimore and the larger state context allowing for the comparison of critical measures such as the number of housing units, and the distribution of housing units across single-family and multi-family housing sectors. As documented in Table 5, Baltimore represents roughly 11 percent of Maryland's population and roughly 12 percent of Maryland's housing stock. Nevertheless home ownership rates in Baltimore are much lower than for Maryland as a whole (roughly 50 % in Baltimore compared with 72 % in Maryland. Moreover, a larger proportion of Baltimore's homes (33 %) are multi-family units compared with just 26 percent for Maryland as a whole. In addition, it is valuable to note that the median value of owner occupied housing in Baltimore is roughly half that of the larger state and that while the number of people per household is roughly the same in Baltimore (compared with the larger state), the median household income in Baltimore is only 56 percent of the median income for the state. One final point of interest is that the poverty rate in Baltimore is much higher than for the state overall, such that more than 1 in 5 residents of Baltimore live in poverty while less than 1 in 10 Maryland residents do. These measures provide important insights into the housing conditions of Baltimore residents as well as their likely propensity to engage in particular energy saving behaviours such as investments in energy efficient technologies.

Given the Census data reviewed here, we would expect that the proportion of Baltimore residents who are renters is much higher than in the rest of the state, and that much of the housing stock in Baltimore was built without energy efficiency in mind. In addition, the relatively low income levels and high rates of poverty in Baltimore diminish the likelihood that residents can afford to finance investments in more energy efficient technologies. These same insights may also suggest that many cash-strapped residents of Baltimore may be disproportionately interested in reducing their energy consumption and more likely to do so using a variety of non-investment approaches.

Model Results and Findings

The Municipal Behaviour Wedge Model was run for five U.S. cities: Boston, Massachusetts; Baltimore, Maryland; Charlotte, North Carolina; Miami, Florida; and Park City, Utah. The cities for whom the analysis were run were members of the Urban

Table 4. Housing Characteristics: Urban Maryland (MD) and the City of Baltimore.

Age of Residence	Avg. Home Size (SqFt)	Urban MD Single-Family	Urban MD Multi-Family	SF + MF Total	Baltimore
2000-2009	2465	4.7%	17.1%	7.8%	3.4%
1990-1999	2200	16.8%	11.1%	15.4%	3.3%
1980-1989	1770	20.5%	10.5%	17.9%	4.6%
1970-1979	1685	7.6%	13.2%	9.0%	6.5%
1950-1969	1350	22.1%	17.9%	21.0%	26.9%
Older than 1950	1020	28.3%	30.2%	28.8%	55.4%
Average/Total	1650	100.0%	100.0%	100.0%	100.0%
Estimated Avg. Home Size Baltimore (SqFt)		1697	842		1276
% of HH Reporting Adequate insulation		77.3%	80.7%	78.4%	

Source: U.S. Census. Notes: Average home size in the US has been increasing over the past 60 years. Most of Baltimore's housing stock is from 1970 or earlier and is smaller than overall national averages or even state averages.

Table 5. Population Demographics: Maryland and Baltimore.

	Baltimore	Balt/MD	Maryland
Population	619,493	11%	5,828,289
Housing Units	296,450	12%	2,391,350
Home Ownership Rate	49.80%	72%	69%
Housing Units in MF Structures	33.10%	129%	25.70%
Median value of owner-occupied Housing	160	49%	329
Persons per Household	2.52	96%	2.62
Median Household Income	$ 39,386	56%	$ 70,647
Persons below Poverty	21.3%	248%	8.6%

Source: Census Bureau 2011

Sustainability Director's Network and were selected because they volunteered to be part of this foundation-funded study.

Table 6 presents medium-term estimates of achievable energy savings for each of the five cities. In the interest of brevity, data are only provided for the medium term and single-family and multi-family estimates are combined into a single overarching measure of savings. Nevertheless, it is important to keep in mind that the full-version of the Residential Behaviour Wedge Profile Reports provide a much more extensive set of results including separate estimates for both short-term and medium-term energy savings and for both single-family and multi-family homes. (The full set of reports are publically available upon request.)

Table 6 includes several summary-level statistics including estimates of total achievable savings, energy savings as a proportion of energy consumption, and average annual household savings by city. Looking across the 5 cities, we found that savings ranged from 7.5 percent of total consumption in Park City, Utah to 11.5 percent of total consumption in Miami, Florida. The largest savings opportunities (in absolute numbers) were found in large cities located in more northern climate zones (Boston and Baltimore). Similarly, estimates of average annual savings per household showed the highest level of achievable savings opportunities in Boston and Baltimore (8,611 and 7,715 megajoules, respectively) followed by Park City, Charlotte, and Miami.

Local Climate Characteristics also play an important role in determining which behavioural measures contribute the most to achievable savings opportunities. As expected, the behaviours that offered the largest savings opportunities varied dramatically from city to city based on the climate characteristics of the city in question. Not surprisingly, in Miami, Florida, the largest savings were associated with cooling-related behavioural measures and choices, while the savings opportunities in Boston, Massachusetts and Park City, Utah were heavily tied to heating-related behavioural measures. Due to their more varied climates, the savings opportunities in Baltimore, Maryland and Charlotte, North Carolina were much broader in their scope, involving savings from both heating and cooling as well as a spectrum of other energy end uses. These results suggest that achieving a given level of behaviour-related energy savings in cities with more varied climates may require more complex (and potentially costly) programs than achieving the same level of savings in cities located in more uniform climates, all else equal. In varied climates, seasonal campaigns are likely to play an important role in helping people stay focused on those behaviours that matter most during a particular time of year.

In addition to the impact of climate, the age of the city and the housing stock also appear to influence both average home size and the predominant home type (single-family versus multi-family) and these factors in turn helped shape technology saturation, energy use patterns, and energy savings opportunities. For example, older cities tend to have more multi-family housing and the square footage of houses tends to be smaller. Smaller, multi-family housing units with common walls tend to use less heating energy on average compared with larger, single-family houses. And while older houses often were not built with energy efficiency in mind, dense urban development tends to offset the home-size effect on average household consumption. Smaller housing also tends to be more limited in terms of the gross amount of technology saturation. For example, smaller and older housing units are less likely to have second refrigerators or freezers, less likely to have dishwashers, clothes washers, or dryers, and less likely to have as many televisions, home entertainment systems and light bulbs. For example, in Baltimore 37 percent of single family homes reported having a second refrigerator while 0 % of multi-family homes did. Similarly while estimates indicated that 99 percent of single family homes had their own clothes washer in Baltimore, only 22 percent of multi-family homes did. Estimates of achievable savings reflected these differences in that savings opportunities associated with laundry, refrigerators and electronics were disproportionately lower in cities with high levels of multi-family housing and higher in cities with higher levels of single-family housing.

Finally, it is important to note that the achievable savings opportunities associate with changes in energy practices and energy stocktaking types of behaviours where much greater than the achievable savings estimates associated with the investment decisions represented in the model. The combined opportunities of conservation practices and stocktaking behaviours represented between 78 and 87 percent of the total estimated *achievable* savings opportunity. When comparing conservation practices with energy stocktaking behaviours, the results indicated that savings from energy stocktaking behaviours were

Table 6. Municipal-Level Residential Behaviour Saving Estimates for 5 U.S. Cities.

	Baltimore	Boston	Charlotte	Miami	Park City
Number of Households	296,056	272,481	319,918	187,869	9,496
Total Energy Consumption (terajoules)	29,702	27,786	21,422	7,693	821
% Multi-family	34 %	82 %	34 %	63 %	51 %
Achievable Energy Savings (%)	7.70 %	8.40 %	8.20 %	11.50 %	7.50 %
Achievable Energy Savings (terjoules)	2,284	2,346	1,755	886	62
Avg An Consumption per Household (gigajoules)	100	102	67	41	86
Average Annual Achievable Savings per Household (megajoules)	7,715	8,611	5,484	4,717	6,555
Savings from Every Day Energy Practices	21 %	13 %	32 %	54 %	24 %
Savings from Energy Stocktaking	63 %	66 %	55 %	33 %	61 %
Saving from Behavioural Practices (terajoules)	84 %	78 %	87 %	87 %	85 %
Accelerated Heating Equip. Replacement	221.2	476.7	71.7	n.a.	7.5
Heating Equip. Maintenance	109.0	163.6	79.7	n.a.	4.7
Thermostat Setbacks (Htg)	124.2	129.8	80.4	n.a.	3.5
Programmable Thermostat Settings (Htg)	109.1	88.1	95.4	n.a.	6.6
Heating Weatherization	343.8	626.1	77.4	n.a.	7.8
Heating Conservation Actions	247.8	354.2	137.2	n.a.	4.7
Window Insulation (Htg)	98.8	95.9	48.3	n.a.	2.2
Accelerated Cooling Equip. Replacement	31.5	1.1	72.3	47.6	0.1
AC Maintenance	9.4	0.9	25.0	43.2	0.2
Thermostat Setbacks (cooling)	10.9	0.3	30.0	18.4	0.1
Programmable Thermostat Settings (cool)	17.4	3.1	23.4	42.1	0.3
Ceiling Fans	70.0	15.2	122.6	203.7	1.1
Cooling Weatherization	19.5	0.1	17.8	17.6	0.1
Cooling Conservation Actions	13.6	1.1	39.7	34.6	0.1

	Baltimore	Boston	Charlotte	Miami	Park City
Window Film/Blinds	33.4	2.3	74.2	117.2	0.5
Unplug second Refrigerator	190.6	65.1	106.3	40.1	3.8
Water Heater Settings	26.6	22.1	19.4	6.1	0.9
Water Heater Insulation	42.4	21.7	43.2	5.4	1.7
EE Clothes Washer	9.8	3.7	6.3	1.4	0.3
Cold Water Clothes Washing	50.1	29.3	46.3	30.7	2.6
Load Reductions	27.4	17.8	28.5	17.9	1.4
Air Dry Laundry	49.0	31.1	60.6	26.2	2.2
Replace Desktop Computers	10.8	12.0	12.9	5.8	0.4
Vampire Load Management	62.8	51.6	67.9	32.9	1.9
Plug load Management	26.5	26.0	31.0	15.7	1.0
CFL Bulb Replacement	96.0	51.1	88.4	43.7	2.7
Turn off Unused Lights – Indoors	20.3	11.2	17.8	9.2	0.6
Turn off Unused Lights – Outdoors	30.2	5.4	39.6	20.8	1.0
Energy Eff. Pool Pumps	68.2	10.7	60.0	34.3	0.5
Pool Pump Timers and Settings	81.2	12.3	71.5	32.6	0.5
Pool Covers	0.4	0.4	n.a.	2.1	n.a.
Hot Tub Timers	16.2	5.8	57.0	12.7	0.7

Note: All number are presented in terajoules unless otherwise indicated.

two to three times the savings associated with conservation practices – except in Miami, where energy practices represented roughly half of all the estimated achievable savings opportunities. Savings from energy conservation practices ranged from a low of 13 % in Boston to a high of 54 % in Miami. Of course these findings depend in part on the selection of behavioural-measures that were included in the model but they also reflect the limited levels of historical participation in programs that require investments in new technologies and suggest that conservation practices and energy stock-taking behaviours can make an important contribution to energy savings.

Conclusions and on-going research

Overall, the ideas presented in this paper confirm that the energy savings opportunities associated with behaviour-based approaches could result in significant reductions in energy use and carbon emissions and that a low-cost means of providing valuable, city-specific assessments of such opportunities is viable. According to the set of recent, national-level assessments reviewed earlier in this paper, potential savings from the residential sector and personal transportation alone have been estimated at between 20 and 30 percent of current levels of energy consumption and carbon emissions. Similarly, the city-level model presented in this paper estimates the aggregate level of achievable savings for residential-sector households in five U.S. cities (excluding personal transportation) to vary from 7.5 percent to 11.5 percent of current levels of residential consumption in those cities (in the medium term). While the scale of national-level savings opportunities has become increasingly well documented, city-level assessments like those provided by means of the Municipal Behaviour Wedge Profile provide a new and compelling means of accounting for significant differences in regional and sub-regional characteristics including those associated with climate, building stock, technology saturation, technology use, and conservation attitudes and practices.

Notably, the development and application of the Municipal Behaviour Wedge model discussed in this paper has provided cities with a low-cost means of identifying and targeting behavioural opportunities for addressing energy and climate challenges and has resulted in the development of a set of practical estimates of achievable energy savings for five U.S. cities. These cities are beginning to use the model estimates to assess program options, develop strategic and targeted city-level programs focused on shifting critical energy-related behaviours, write research-based funding proposals that provide quantitative impact assessments, and to test the rigor of the model estimates. Nevertheless, it is important to note that like most estimation models, the estimates provided by the Municipal Behaviour Wedge model rely on a variety of underlying assumptions and particular data sources that can affect the quality of the estimates. Of particular note is the fact that this model relies on data collected by means of the Residential Energy Consumption Survey which is only performed every four or five years and often delayed in its release to the public. As a result, these estimates cannot account for changes in technology saturation and use patterns that have occurred in the period since the data were collected. As with all estimates, it is important to recognize the short-comings and limitations of this information and caution should be taken in their application and interpretation.

References

Adler, Ben. 2014 "Cities are lapping countries on climate action." GRIST (Sept 29). Available at: http://grist.org/cities/cities-are-lapping-countries-on-climate-action/.

Dietz, Thomas; Gardner, Gerald T.; Gilligan, Jonathan; Stern, Paul C.; and Michael P. Vandenbergh. 2009. "Household actions can provide a behavioral wedge to rapidly reduce U.S. carbon emissions." Proceedings of the National Academy of Sciences 106 (44), November.

Ehrhardt-Martinez, Karen and Adam Meier. 2013. "Behavior Wedge Profile: Model Development and Documentation." Prepared for the Urban Sustainability Directors Network. Garrison, NY: Garrison Institute.

Ehrhardt-Martinez, Karen. 2012. Personal communications with members of the Urban Sustainability Directors' Network (USDN).

[EIA] Energy Information Administration. "2009 Residential Energy Consumption Survey Microdata." Available at: www.eia.gov/consumption/residential/data/2009/index.cfm.

Gardner, Gerald and Paul Stern. 2008. "The Short List: The Most Effective Actions U.S. Household Can Take to Curb Climate Change." *Environment Magazine*.

Hower, Mike. 2014. "Tracking city climate actions: There's a new website for that." Greenbiz (December 24). Available at: http://www.greenbiz.com/article/new-platform-aggregates-city-climate-action-data.

Jaffe, A. B. and R. N. Stavins. 1994. "The energy-efficiency gap: What does it mean?" *Energy Policy* 22 (10): 804–810.

Lacy, Stephen. 2014. "10 US Cities Plan Coordinated Attack on Building Energy Waste." GreentechEfficiency. Available online at: http://www.greentechmedia.com/articles/read/10-US-Cities-Plan-Coordinated-Attack-on-Building-Energy-Waste.

Laitner, John A. "Skip", Karen Ehrhardt-Martinez, and Vanessa McKinney. 2009. "Examining the Scale of the Behaviour Energy Efficiency Continuum." in *ECEEE 2009 Summer Study: Act! Innovate! Deliver! Reducing Energy Demand Sustainably*. La Colle sur Loup, France: European Council for an Energy-Efficient Economy.

[NRDC] Natural Resources Defense Council and the Garrison Institute. 2010. "Simple and Inexpensive Actions Could Reduce Carbon Emissions by One Billion Tons." New York, NY: Natural Resources Defense Council.

Acknowledgements

This paper was prepared for the 2015 eceee Summer Study on Energy Efficiency. Much of the content of this paper represents ideas, processes, and methodologies that were first documented and discussed in (Ehrhardt-Martinez and Meier 2013). The author would like to acknowledge the contributions of Adam Meier, Derrick Carlson and John A. "Skip" Laitner in the development of the Behaviour Wedge Model and recognize the important role of the Urban Sustainability Directors Network (USDN) and the representatives of USDN cities who provided guidance and insights throughout the research process. Funding for the underlying research and the development of the prototype model was generously provided by the Mertz-Gilmore Foundation. Funding for the development of the full model was provided by The Kresge Foundation and the Funder's Network for Smart Growth and Livable Communities.