Seeing is Believing: Mapping Building Efficiency Potential Across a Metro Region

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ABSTRACT

Just as cities can map distributed solar potential based on rooftop orientation and shading, regional energy efficiency potential can be mapped based on patterns of building types and their anticipated efficiency needs. Understanding the geography of efficiency brings an opportunity to leverage development patterns for enhanced community-scale programs. This paper reviews a GIS-based tool that can visualize, measure and compare different program tactics at the community scale. It was developed for the Twin Cities metro using tax parcel and LiDAR data, and builds on data showing that cost-effective efficiency priorities can change based on a building's use, era of construction, and size. At the regional scale, these dominant building styles form patterns governed by how land use has changed over time. Project results measure how the region's distinct land use patterns, from a mix of farmland and exurban development to an older urban core, change the potential for different efficiency tactics. The tool can help communities prioritize programs, as well as identify similar areas suitable for potential coordination.

Introduction

Local energy efficiency opportunities and program strategies depend on the characteristics of the local building stock: whether it includes dense urban housing, planned suburban developments, or a mid-sized commercial corridor. The geography of energy efficiency refers to how these differences are influenced by the underlying patterns of dominant building styles, governed by changes in land use development over time. Characterizing the geography of energy efficiency at the local and regional scale has numerous applications. It can assist a local unit of government in setting efficiency program goals and targets; help a utility forecast where on their system they might see peak load reduction from load control programs; or allow a program provider to understand where and how to deploy targeted marketing strategies.

This paper reviews a Geographic Information System (GIS) tool developed to assess community-scale energy savings strategies for the Twin Cities Metropolitan Area. The *Twin Cities Building Energy Map* identifies local efficiency priorities based on the core characteristics of the building stock, namely, the mix of use types, eras of construction, and building sizes that are dominant in a particular region. For example, program experience shows that residential wall insulation is still a high priority for pre-war homes in the Twin Cities metro, but less so for suburban homes built to codes issued after the 1970's energy crisis. Similarly, commercial construction style has evolved dramatically over the last century, from smaller masonry buildings to large steel frames, each with distinct efficiency priorities. Community-scale energy planning can benefit from understanding these patterns and their implications for energy use.

One valuable feature of the Twin Cities Building Energy Map is that it can be enhanced by actual energy usage data, but does not rely on measured data to provide results. The availability of customer energy usage data is often subject to both privacy and technical limitations, and has been the focus of recent regulatory interest in many states, including Minnesota (SEE Action 2012). Instead of actual energy use, this tool uses the estimated potential of common efficiency strategies for different building types. The goal is to allow local decision-makers to understand and prioritize the energy efficiency strategies for their region. Some unique contributions include:

- A building and energy assessment tool for the regional scale, beyond individual city or utility territory.
- Exploration of techniques and limitations for aggregating disperse data sets across a seven-county metro region.
- A "bottom-up" assessment of energy saving potential that compliments actual usage data when available, but is focused on measuring energy savings potential rather than use.

Trends in Regional Energy Mapping

Recent trends in energy mapping are closely tied to the expanded availability of both energy and remote-sensing building data. Low granularity tracking at the city scale allows cities to compare energy use to each other and their own year to year (Regional Indicators Initiative, 2014). In Los Angeles, monthly data from the local utility is provided at the census block group level, and allows users to see changes over time (Pincetl et al 2012). In tandem, the growing availability of building data from satellite and Light Detection and Ranging Data (LiDAR) sources have created high-resolution maps of the built environment. Recent projects in New York City and Paris have used building stock data to disaggregate citywide energy use at a finer scale (Howard et al 2012, Salat 2009). Other projects have mapped individual customer usage data along with demographics to deliver a marketing campaign (Kelsven 2012).

These projects reveal where energy is *used*, but not necessarily where it can be *saved,* and more specifically, through which specific program or policy strategies. Furthermore, these maps depend on the availability of energy data at the scale of interest, which varies significantly based on local laws and utility tracking systems, not all of which can readily link usage to geography. Multiple utility service territories may also serve one region, as occurs in the Twin Cities. These issues underscore the value of a geographic planning tool that can be built from the bottom-up from energy savings potential, without relying on the availability of actual usage data.

Mapping of clean energy potential has occurred for renewable energy systems, most notably rooftop PV. There are numerous examples of local solar potential maps that use LIDAR data to estimate size, orientation, and shading, down to the building level (Dean et al 2009, Jakubiec 2013). These maps are intended to help owners or planners decide where the greatest attention should go, but this technique has been applied less frequently to energy efficiency.

One recent trend is that the abundance of building and energy data are allowing researchers to create maps at finer and finer resolution, down to the building level. This raises the question of the appropriate level of aggregation for a given map's application and quality of data inputs. For many applications, including efficiency potential, averages based on building stock patterns are not valid for the individual building, but only for averages across a higher geographic resolution that includes a large number of buildings. This tool aggregates data at the census block level partially for this reason.

Creating a Spatially Linked Building Database

The first step in developing the Twin Cities Building Energy Map was to create a spatially linked building stock database for the Twin Cities, a seven-county metro area that includes over 125 cities and townships with a total population of 3.3 million. The challenge was to create a single database from disparate sources with inconsistent building classification schemes, which were developed for tax assessment, not energy use purposes. While the property parcel inventory was fairly complete across the region, property records had significant data gaps in building square footage, year built, and property type. These additional attributes were filled in using five data sources. In hierarchical order, these datasets were:

- 2009 GIS tax parcel data from the Metropolitan Council (Met Council), the regional planning organization for the seven-county Metro Area. Met Council provided spatial records of 1.12 million parcels, compiled from county and city assessing offices.
- Individual county and city records that filled in considerable square footage gaps in the Met Council file. These were joined to the Met Council shapefiles based on parcel identification number (PIN).[1]
- Light Detection and Ranging Data (LiDAR) of building footprints generated by the Minnesota Geospatial Information Office.[2] LiDAR is an active remote sensing technology that uses laser light to detect and measure surface features on the earth at high resolution. LiDAR imaging was used to estimate remaining building square footage gaps in the Met Council and individual government files.
- US Census Bureau data at the block group level for demographics and housing characteristics.
- Publicly accessible geographic boundary shapefiles including census block groups, neighborhoods, cities, and counties.

Figure 1 shows the order of operations for merging these datasets when the original Met Council tax parcel data was incomplete, for the building square footage attribute.

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[1] The following counties and cities generated reports for this project: Anoka County, Dakota County, Ramsey County, Scott County, Minneapolis, Minnetonka, Eden Prairie, Brooklyn Park, Edina, Plymouth, St. Louis Park, Bloomington, and Maple Grove.

[2] Available at http://www.mngeo.state.mn.us/chouse/elevation/lidar.html. At the time of this analysis, LiDAR data for the Twin Cities region contained only X and Y coordinates; the Z (height) dimension was not available.

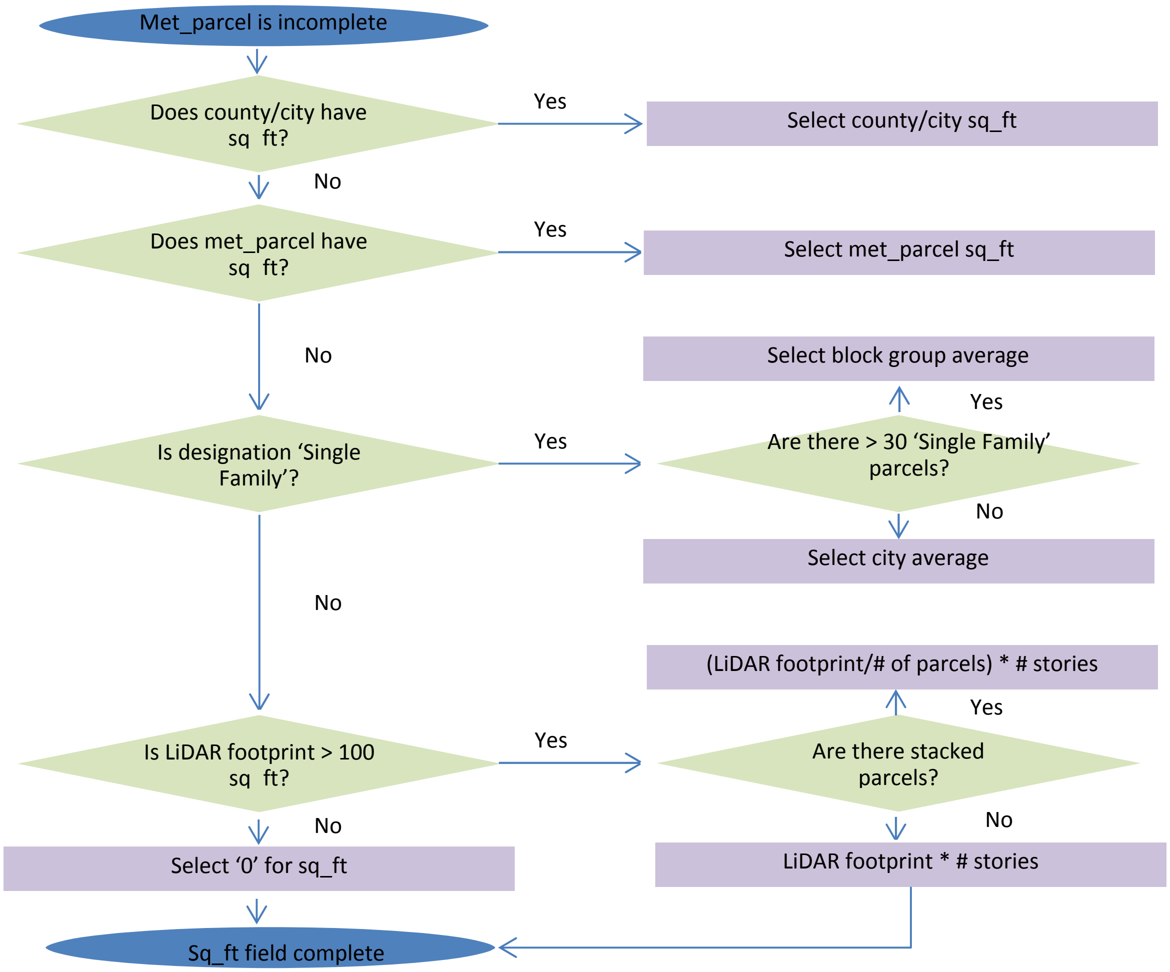

Figure 1. Order of operations to build twin cities property database

LiDAR data were valuable for estimating the building size for individual parcel records, though many approximations were needed. LiDAR showed building footprints, but in many cases these were outbuildings (e.g. garages) or in some cases the building footprint was incorrect (e.g. it included adjacent trees). Also, the dataset lacked the z-coordinate (or height), which meant that building stories had to be estimated. Commercial buildings were given an average number of stories based on building type and location. Single family and multifamily residential homes were given the average square footage from other homes in the same census block group that did have square footage information, provided there were over 30 records.

The complete building database captured 3.14 billion square feet of property in the Metro Area. This is considerably higher than the 1.55 billion square feet found in the initial Met Council dataset. There were over 347,000 parcels in the Met Council file, or 30 percent of all parcels, that had no square footage but were found to have a square footage from other sources. The composition of square footage from various original sources is shown in Figure 2 below.

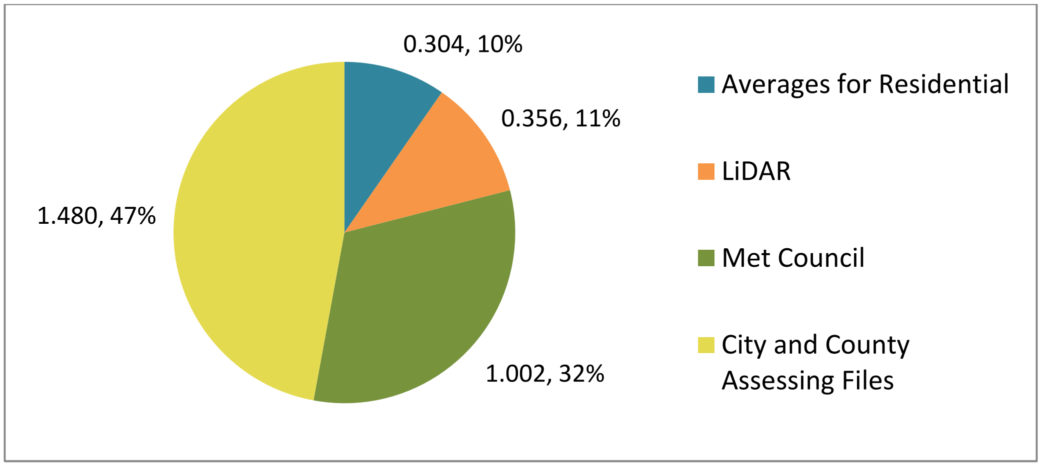

Figure 2. Building database composition- square footage (billions) by source.

This uncertainty in building square footage and other attributes was partially managed by setting the Building Energy Map at a higher geographic resolution. Summary data were aggregated at the census block group, which contain between 600 and 3,000 people,[3] rather than providing statistics at the block or parcel level. Census block groups provide sufficient granularity for planning and assessment purposes, even planning at the city or neighborhood level. More importantly, the energy savings estimates layered in the next analytic step are all based on averages for energy savings potential. Even if the regional datasets contained precise square footage information, additional granularity would have indicated false precision of this energy data.

Age Composition

Ages were summarized by the total number of square feet in distinct size buckets, corresponding to eras of building that help determine energy use, and more importantly, the standard efficiency measures that are most applicable to a building. These time periods are pre-1945 (before WWII), 1945 – 1975, 1975 – 2000, and post 2000. These capture eras of distinct building types and energy codes. Figure 3 shows the example of age distribution for single family homes across the metro. It shows that the oldest homes are clustered in the central metro region, which is surrounded by newer developments. However, there are pockets of older town centers dispersed throughout.

[3] U.S. Census Bureau, "Geographic Terms and Concepts." http://www.census.gov/geo/reference/gtc/gtc_bg.html. Accessed March 2, 2014.

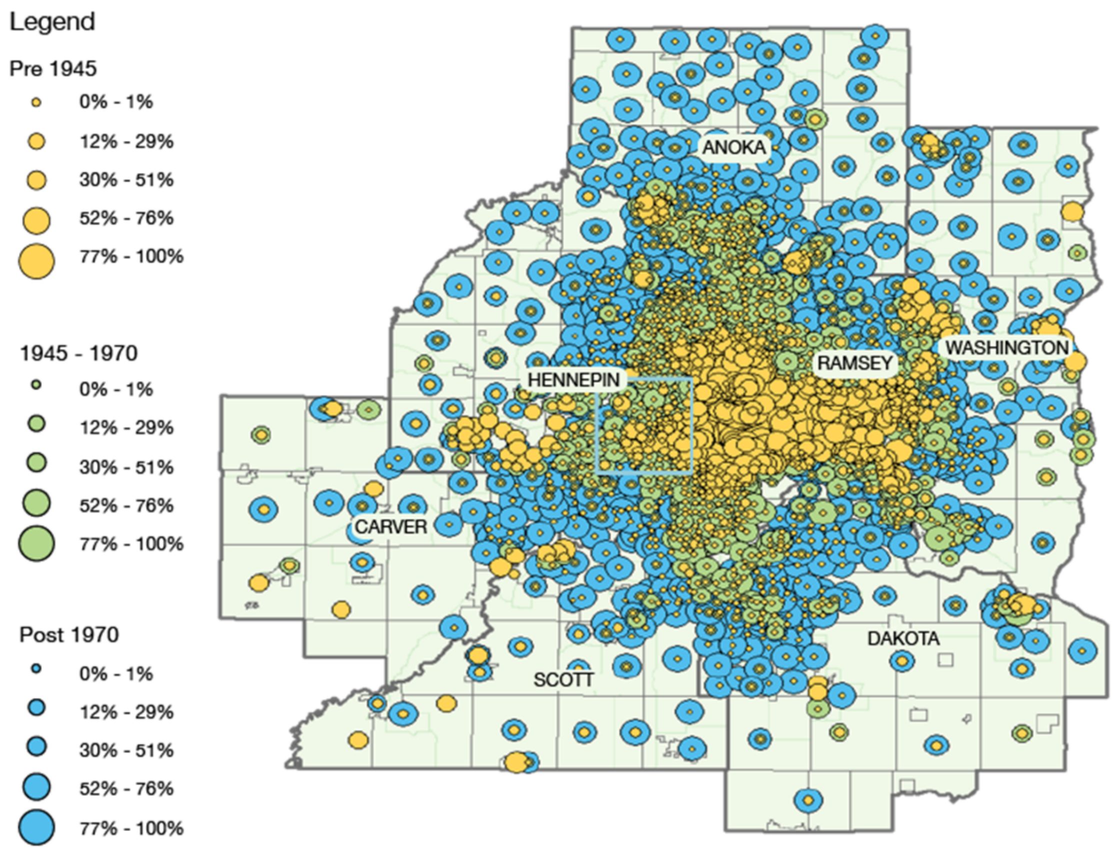

Figure 3. Average age of single family homes across metro region.

Building Demographics

Developing a uniform set of building types required correlating the varying classifications contained in the individual datasets with categories that were relevant for energy efficiency. There were a total 758 building use categories identified in the combined Met Council and individual city and county assessor files. These building use categories were broken in to 15 use designations. Where possible, commercial uses were classified to match the EIA's Commercial Buildings Energy Consumption Survey (CBECS) building classification scheme.[4] This allows the CBECS national energy survey data to be merged with the mapping tool. However, even with much greater property use detail, there was often not enough information to match to CBECS data. See Table 1 below for a comparison to CBECS categories.

Table 1. Comparison of use categories to CBECS

Twin Cities Building Energy Map	Shared Categories	CBECS
Agricultural Building	Educational	Health Care (Inpatient)
Single Family	Office	Health Care (Outpatient)
Multifamily	Lodging	Public Assembly
Industrial	Religious Worship	Public Order and Safety

[4] Using 2003 data, the most recent available.

Twin Cities Building Energy Map	Shared Categories	CBECS
Hospital / Clinic Public Services Recreational Other Commercial Miscellaneous / Storage Retail	Vacant Buildings	Food Service Food Sales Mercantile (retail other than mall) Mercantile (enclosed & strip malls) Service Warehouse and Storage Other

The most challenging data were records for condominiums. One building often has multiple entries, one for each condominium owner. This form of accounting is important for tax assessors, but can lead to over- or under-counting building square footage. Multi-use buildings were also a problem. Only some assessing offices had separate categories for multi-use buildings. Some offices listed multiple categories for one building, with the dominant use first. Some simply did not identify multi-use buildings. This complexity led us to assume the first classification used by assessing offices was the dominant use, and we classified the building as such.

Buildings were separated into use categories and square footage totals were calculated for the Metro Area and summarized by census block group. Single family homes contributed the largest proportion of square footage across the Metro area (45 percent) and within Minneapolis and St. Paul only (33 percent). Multifamily homes followed, contributing 18 percent to the Metro Area and 21 percent to the Twin Cities. Commercial square footage is likely underestimated.

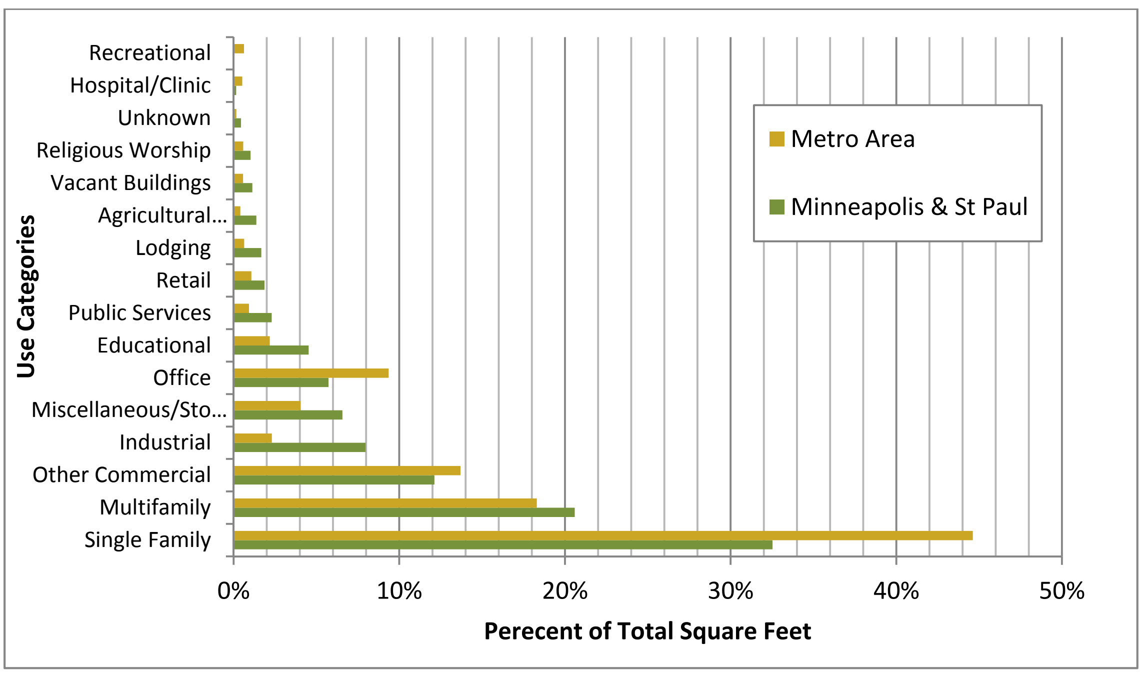

Figure 4. Percent of total square feet by use category.

Developing Energy Efficiency Scenarios

The second step of the Twin Cities Building Energy Map is to create energy efficiency scenarios based on energy use and average energy savings potential by building type, age, and size. The building characteristics database described above assigns each metro census block group a total number of square feet and total number of buildings for each building use type and age category. The energy scenarios are used to assess the geographic patterns of energy efficiency potential, conduct an inventory of use types, or determine where certain program design and outreach strategies may be most effective. Energy data and assumptions are taken from numerous sources, including both public and program-based sources, depending on the scenario. Three example applications are discussed below.

Wall and Attic Insulation in Single Family Homes

Wall and attic insulation continue to be a leading cost-effective energy efficiency opportunity, but the market potential varies depending on the average age of homes. Twin Cities pre-war homes were not insulated, though efficiency efforts since then have reduced the number of candidate homes. Meanwhile, a home built to new energy codes in the 1980's included wall and attic insulation (though field experience shows there continue to be opportunities in some homes, Nelson 2011). Table 2 shows estimates of the remaining potential for wall and attic insulation in Twin Cities single-family homes, based on the year built. These estimates were derived from a program database of 3,600 homes across the Twin Cities (Nelson et al 2014).

Table 2. Estimated number of single family homes that lack insulation, by year built

Age of Home	≤ 1939	1940-1959	1960-1979	1980-1999	≥ 2000
Homes with Inadequate Attic Insulation	48%	39%	15%	2%	-
Homes Lacking Wall Insulation	37%	4%	5%	-	-

While the average age of a home was used to estimate the number of potential candidates in each census block group, the average size of a home determined how much energy could be saved. We used the following equations for annual energy savings potential per home, which are based on local program data and energy modeling conducted for a local energy certificate program specific to the Twin Cities (Edwards et al forthcoming, Nelson et al 2014):

$$\textit{Annual Savings from Wall Insulation (therms)} = 0.11 sf_{avg} + 197.3,$$
$$\textit{Annual Savings from Attic Insulation (therms)} = 0.02 sf_{avg} + 89.3,$$

where sf_{avg} is the average size in square feet of the homes within each age category in a census block group.

Figure 5 below shows the results across the metro region of the estimated total energy savings potential of single-family wall and attic insulation, normalized by the size of the block group. The map shows that regionally, the high potential lies with older homes in the central older cities. This includes the core metro of Minneapolis and St Paul, but also outlying cities such as Excelsior, Stillwater, and Chaska. By displaying annual therms per acre, these results will closely track patterns of density across the metro. This type of display can help communicate to a local unit of government how much total potential lies within their jurisdiction, in the hopes of motivating a leading city to take action.

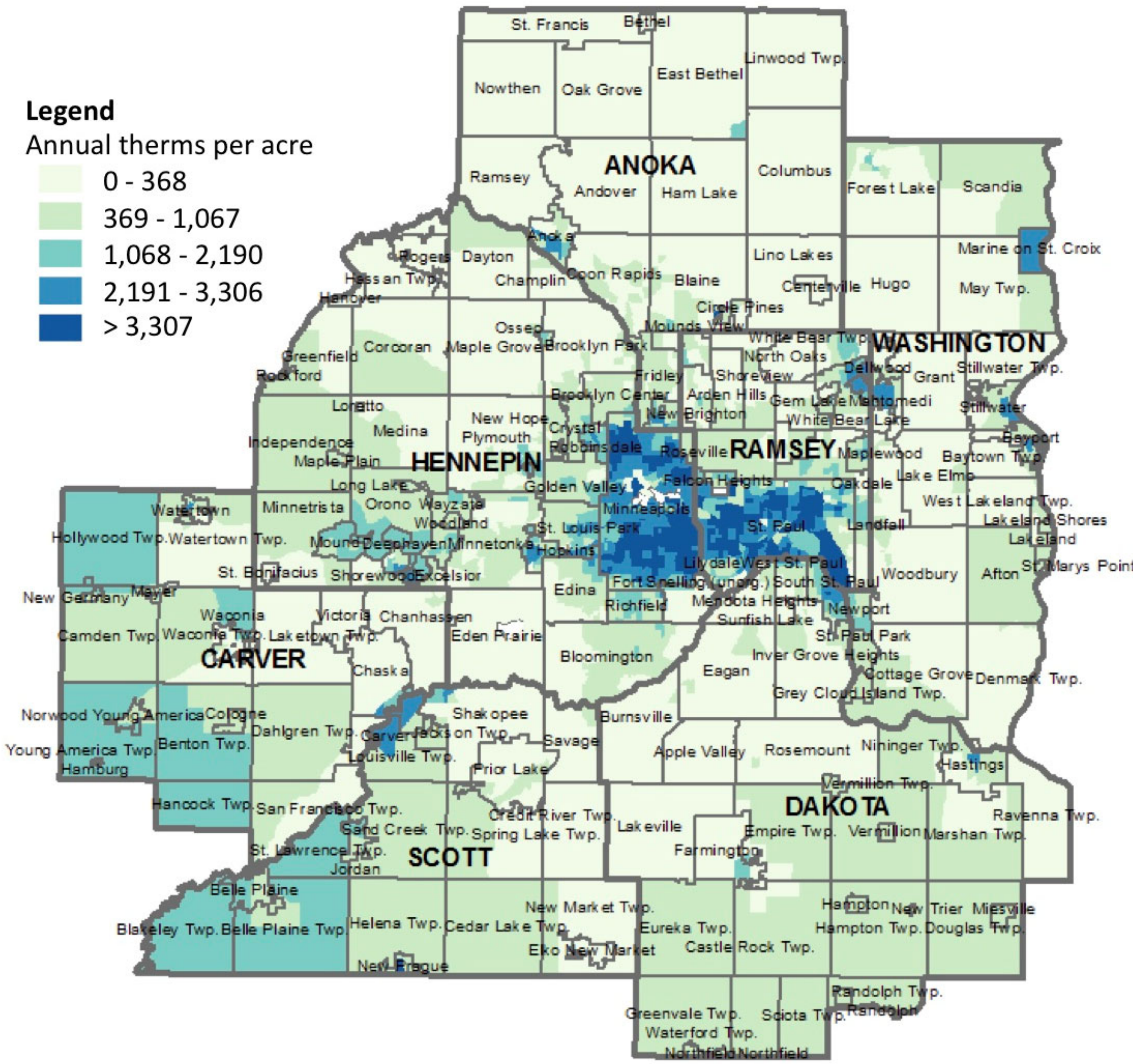

Figure 5. Annual energy saved per acre from single family home insulation.

Commercial Size Classes

The Twin Cities Building Energy Map was also used to examine the distribution of commercial building size classes throughout the metro, to help inform where to target different program and policy opportunities. An examination of recommissioning opportunities in Minnesota public buildings found that larger buildings over 100,000 square feet often have additional savings opportunities, upwards of 10 percent (Plum et al 2012). These larger buildings are also more likely to track their energy use, and more recently, to be subject to city benchmarking requirements (as the City of Minneapolis has recently required beginning in 2014). In contrast, regions dominated by small commercial buildings (under 10,000 square feet) will need programs and outreach strategies tailored to small businesses, and do not have the same level of equipment tune-up opportunities as in large buildings.

As Figure 6 below shows, the distribution of commercial size classes across the metro region is highly dependent on geography. Utilities working within individual communities can plan and prioritize programs that are tailored to the specific building stock.

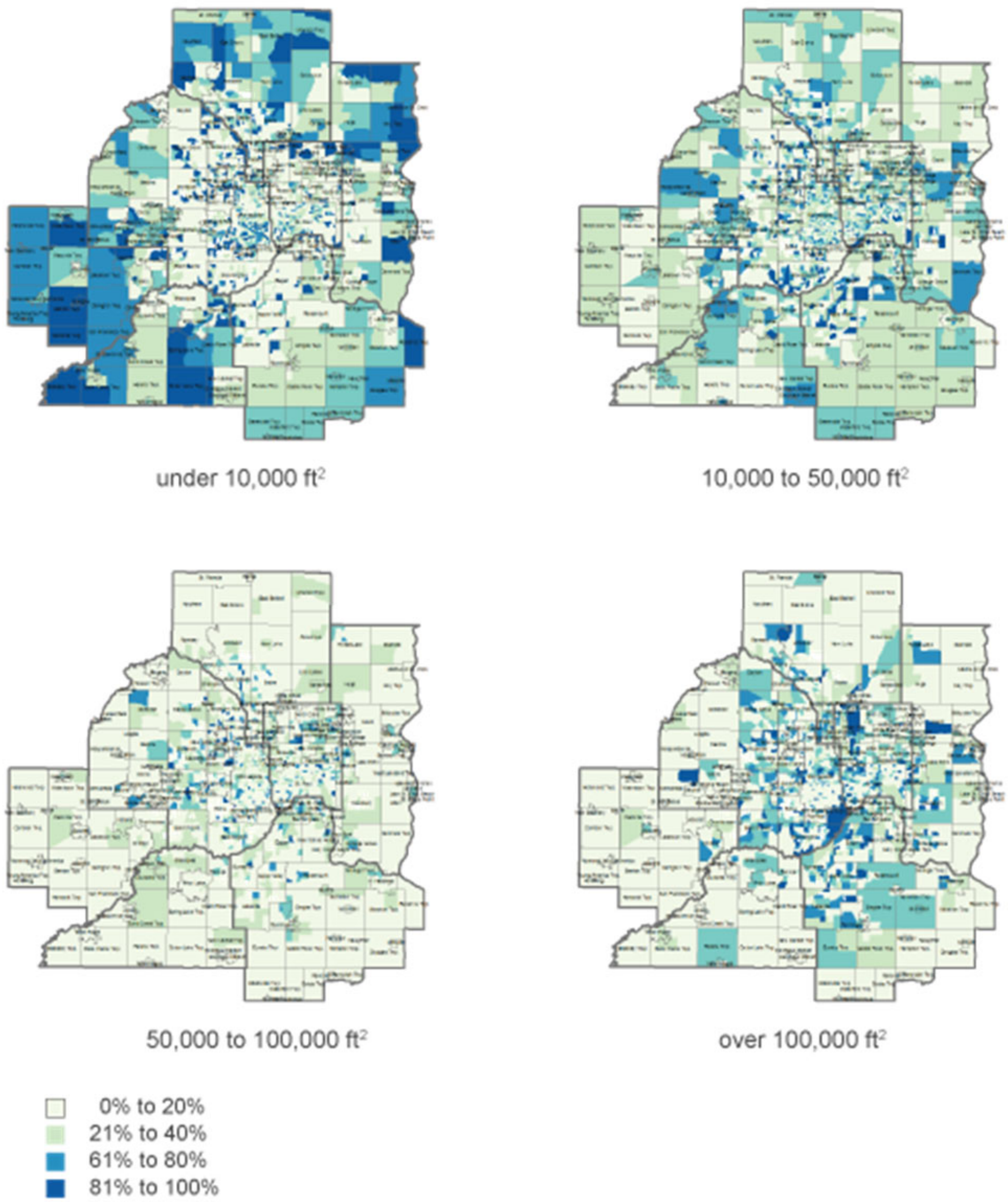

Figure 6. Metro distribution of commercial building size classes.

Citywide Residential Energy Savings Potential

At the city scale, decision-makers are often interested in how the benefits of different program strategies will be distributed to neighborhoods across a city. The City of Minneapolis recently commissioned a study to determine the best opportunities for meeting citywide clean energy goals (Bull et al 2014). As part of this study, there was growing interest in working with utilities to develop a multifamily energy efficiency program, which does not currently exist.

The Twin Cities Building Energy Map was used to show how energy savings from multifamily programs could contribute to each neighborhood's total residential electricity and natural gas savings. Minneapolis has approximately 83,000 multifamily units and 88,000 single family and duplex homes, distributed across 81 neighborhoods. We estimated the total energy savings potential per unit based on recent program and pilot experience.[5] The results are shown in Figure 7.

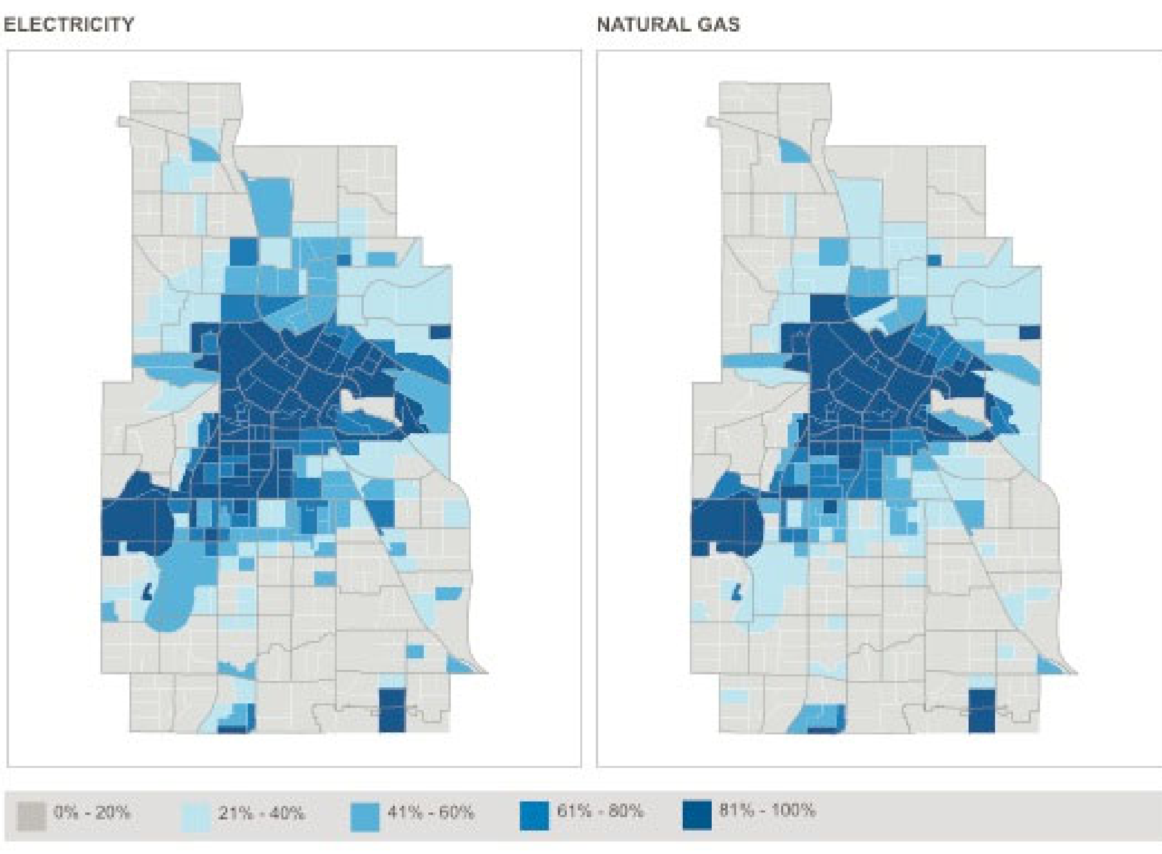

Figure 7. Estimated multi family energy savings potential as a percent of total residential potential by Minneapolis neighborhood.

[5] We estimated annual multifamily energy savings at 60 therms and 390 kWh per unit, based on results from a recent multifamily pilot (Nelson 2013). Single-family gas savings were estimated as described for wall and attic insulation above, and we assumed an average electricity savings of 580 kWh per home.

Summary and Next Steps

The Twin Cities Building Energy Map provides a useful tool for energy planners and policy decision-makers to understand the regional energy potential of different programs and strategies. It is built from underlying building stock information across a regional metro area, made uniform from disparate data sources, and organized by age and building type so that energy scenarios can be applied. The tool can support numerous different energy scenarios, limited more often by the availability of energy data. The programming logic behind the building database allows for updates as new versions of underlying building data become available.

Key limitations relate to the availability and uniformity of building stock data. Tax assessor data, the primary source for local government property databases, is not collected or presented in a way that is ideal for energy assessments. Assumptions were made to deal with certain limitations including missing building classification and square footage data, and challenging classifications such as condominiums. Nonetheless, the resulting buildings database more than doubled the square footage information available in the best available existing parcel database, and is the most complete and consistent across the metro region for energy planning purposes.

One primary advantage of energy efficiency mapping is to better communicate the potential for "invisible" energy efficiency measures such as building insulation, and to highlight regions that have a distinct advantage based on their housing stock. Future applications can assist with regional energy planning and assessment across city or county jurisdictions. As local governments increase their access to jurisdiction-wide energy use data, that top-down information can be coupled with the finer resolution, "bottom-up" building energy database to understand where the energy is being used, and where the largest opportunities are for energy savings and carbon reduction potential within the building stock. This can be used for additional applications like those outlined here, such as market potential assessments, metropolitan climate planning, and geographically targeted program marketing.

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