Benchmarking and Audit Data Inform Building Science

Richard Leigh, Sean Brennan, Megha Jain, Laurie Kerr, Jamie Kleinberg, Xiaoyu Qin, Cecil Scheib, Urban Green Council

ABSTRACT

New York City has established itself as a leading local actor in the fight against climate change, adopting a formal goal of reducing greenhouse gas (GHG) emissions 80% by 2050. In support of emissions reductions the city passed Local Law 84 of 2009 (LL84) requiring reporting of energy and water use in properties with buildings of more than 50,000 square feet—roughly 13,000 properties covering 42% of the city's floor area. The city also passed Local Law 87 of 2009 (LL87) requiring the same properties to undergo an energy audit and retrocommissioning every ten years. This paper is a review of the energy use data for 2010 – 2013 and the results of the energy audits for 2013 and 2014.

The LL84 energy use data reveals that source energy use has declined 6% since 2010, while GHG emissions have fallen by 8%, a useful start toward the 2050 goal. The LL87 audit results provide some of the tools needed to continue emission reductions in the years to come. We present data on building structure from the audits, such as the fraction of floor area in audited buildings served by various lighting technologies, and show the value of using sectoral mean energy utilization intensity (EUI) as well as median EUI in assessing energy use. Energy audits included a package of recommended energy conservation measures (ECMs) and, as we discuss, the expected savings from these are lower than savings obtained in many real-life programs.

Introduction

We spend nearly 90 percent of our time inside buildings and we expect to be comfortable while there. Many of us equate comfort to chilled air in the summer and cozy interiors in the winter, but in buildings designed using standards consistent with plentiful and historically inexpensive energy, these comforts lead to overconsumption of fuels and electricity. Stemming climate change requires very substantial reductions in GHG emissions, and in New York City, buildings are responsible for over 87% of emissions from stationary sources and 66% of total emissions (NYCMOS 2016). The benchmarking and energy audit data provided by LL84 and LL87 contribute key information for our goal**:** to achieve these substantial reductions without major sacrifices in comfort or behavior, in buildings that are designed or retrofitted to handle our needs in better managed and more efficient ways.

With Local Law 84 of 2009 (LL84) New York City recognized that the first step in reducing emissions from buildings is to measure those emissions on a building-by-building basis. This reporting system, called "Benchmarking," applies to all buildings over 50,000 square feet of floor area and properties with multiple buildings over 100,000 square feet. This report includes results from 2010 to 2013 and, for LL87 data only, 2014. The Benchmarking data covers overall fuel, electricity, and water use, all as entered into the US EPA's Portfolio Manager system, and the outputs of that system, including site and source energy, emissions, Energy Star scores, and water use, all on an annual basis.

Fifteen U.S. cities and two states now require benchmarking of large buildings (Zeiss 2012, Building Rating 2015). While all large buildings in New York are required to benchmark annually, LL87 also requires a rotating ten percent of that group to perform an energy audit each year. This report includes audit data from 2013 and 2014.

Energy auditing, carried out by engineering firms and consultants, provides three basic types of information: a breakdown of energy use by function, such as heating or lighting, an inventory of envelope characteristics and energy equipment, and a list of proposed energy conservation measures to reduce the building's energy usage and carbon emissions.[1]

Within the building sector, the Benchmarking data reveals that multifamily properties consume 57% of reported source energy and offices consume 38%. Consequently, most reporting is restricted to these two categories, with the remaining sectors lumped together as "Other." While there are eight times as many multifamily properties as offices, the offices use a comparable amount of the source energy, due to the greater electric loads. Where useful, the "Other" category is disaggregated into more detailed components. Data for individual sectors are further divided into low-rise buildings (with seven floors or less), high-rise (eight or more floors), and very large (all buildings over 500,000 square feet, regardless of height).

A substantial part of the Benchmarking data for individual buildings is public and available online (NYC DATA 2016). However, due to privacy concerns, much of the Benchmarking data and all of the audit and RCx data are not public, but are made available to qualified researchers under contract with the city. This paper is based on all data available to date, including this "private" data and providing:

- Historical and sectoral comparisons of building energy use and observations of efficiency opportunities,
- Prevalence of envelope characteristics and energy systems in audited buildings and observations of efficiency opportunities,
- Summaries of engineers' estimates of potential savings from energy conservation measures (ECMs),
- Proposals for use of these results in ongoing improvements in building performance throughout the city, and
- Some details on building populations, data cleaning, and data reduction techniques.

More detail on many of these matters is available in New York City's report on Energy Efficiency in Buildings, the fourth in its series on benchmarking and, now, audit data. (NYC EER, 2016) That report was prepared by Urban Green Council in cooperation with the Mayor's Office of Sustainability and the New York University Center for Urban Science and Progress. All the work reported in this paper is by Urban Green Council, which is solely responsible for its content.

[1] LL87 also requires retro-commissioning (RCx), which aims to ensure that building systems are operating as designed. Perhaps due to the novelty of the exercise, the data resulting from RCx has not proven useful in the broad surveys presented here.

Energy Use and GHG Emissions in New York City's Large Buildings

This section presents the energy use data gathered from LL84 filings and the energy use estimates prepared by energy auditors under LL87, and where possible, points to possible energy or emissions reductions revealed by this data. Source energy use and emissions were calculated from fuel and electricity consumption by the EPA's Portfolio Manager (EPA 2015) as part of the input process, and then summed over sectors as indicated.

Source energy use in benchmarked buildings in 2013 is summarized in Figure 1. Energy used is compared between sectors using the total Energy Utilization Intensity (EUI, kBtu/ft^2) of each sector, calculated as a sectoral EUI[2] from the EUIs of individual buildings. The area of the circles indicates total energy use among benchmarked buildings in the city for each sector. The most energy-intensive sector, supermarkets, use eight times more energy per square foot than the least energy-intensive sector, self-storage. This comparison often reflects the activities associated with a sector rather than superior design practices. Properties with similar uses tend to have comparable energy use intensities, such as multifamily housing and residence halls.

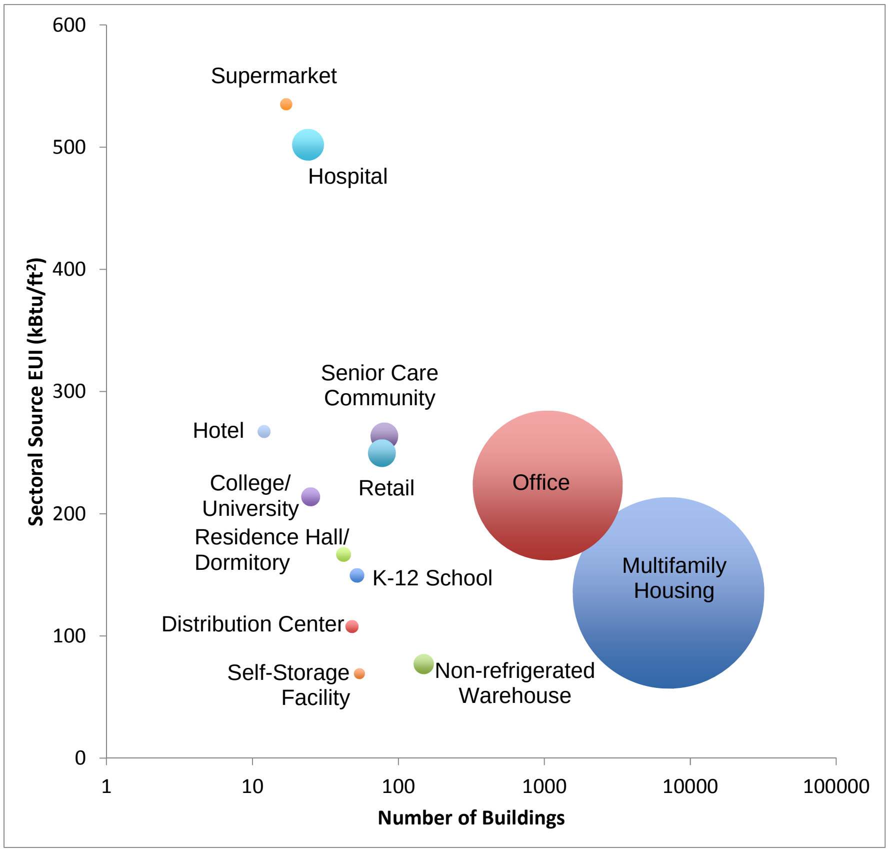

Figure 1: Energy use and EUIs for benchmarked buildings by sectors. Areas indicate total city-wide energy use.

[2] See the Appendix on Data Treatment for an explanation of the use of sectoral and median EUIs.

Multifamily and office properties continue to dominate the benchmarking landscape in 2013. Accordingly, energy efficiency efforts remain targeted toward those sectors. Social factors, economic malfunctions such as master metering or unpriced health impacts, and misplaced responsibilities inhibit the implementation of energy efficiency, but the data reported here show that at a technical level, opportunities abound.

LL84 data show that NYC's large buildings have already made substantial progress in reducing their energy use and emissions. Figure 2 shows weather normalized source energy use and emissions for 2010 through 2014, with overall declines of 6.5% and 9.6 %, respectively. These totals are only for the roughly 2,300 buildings that reported benchmarking data in all five years. Figure 2 also shows, as a solid curve, a representation of annual emissions calculated as declining by a fixed percentage each year.[3]. This curve seems to indicate that these buildings are on a track towards emissions reductions of over 70% by 2050. However, this encouraging news is no reason for complacency. Buildings reporting in all five years may tend to be those with better management. Initial reductions in energy use and emissions are relatively easy, through better operations, staff training, and low-cost upgrades such as lighting. The way forward will be substantially more difficult, as complex Energy Conservation Measures (ECMs) with higher capital cost become necessary for continued progress. The road to 80 by 50 will be challenging.

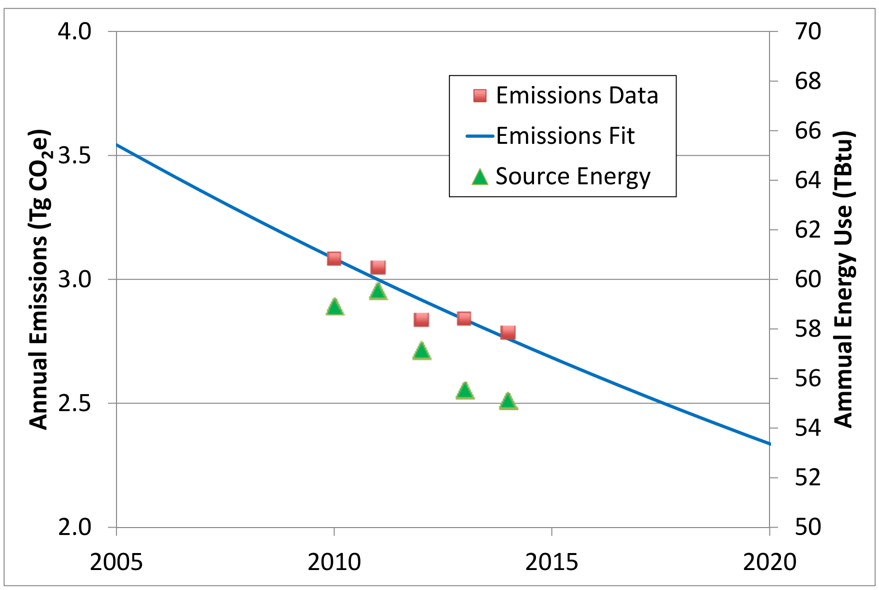

Figure 2: Total emissions and source energy from 2632 benchmarked buildings reporting in all five years, and best-fit emissions declining 2.7% per year.

The individual behavior of the office and multifamily sectors is presented in Figure 3, which shows three-year decreases in source EUI (10.7% for the office sector and 5.6% for multifamily). The median EUIs represent a "typical" building while the sectoral EUIs represent total energy use in each sector. The median office Energy Star scores increased by 3.5 percent over the four year period, while the sectoral mean Energy Star scores grew by 4.6 percent,

[3] This curve is calculated by adjusting both the 2005 emissions and the annual fractional reduction to minimize the sum of the squared differences between the curve and the actual five points of emissions data. The result is an estimate of 2005 emissions equal to 3.54 Tg and a decline of 2.74 %/year,

indicating that the EUIs of large office buildings are declining a bit more rapidly than those of smaller buildings.[4]

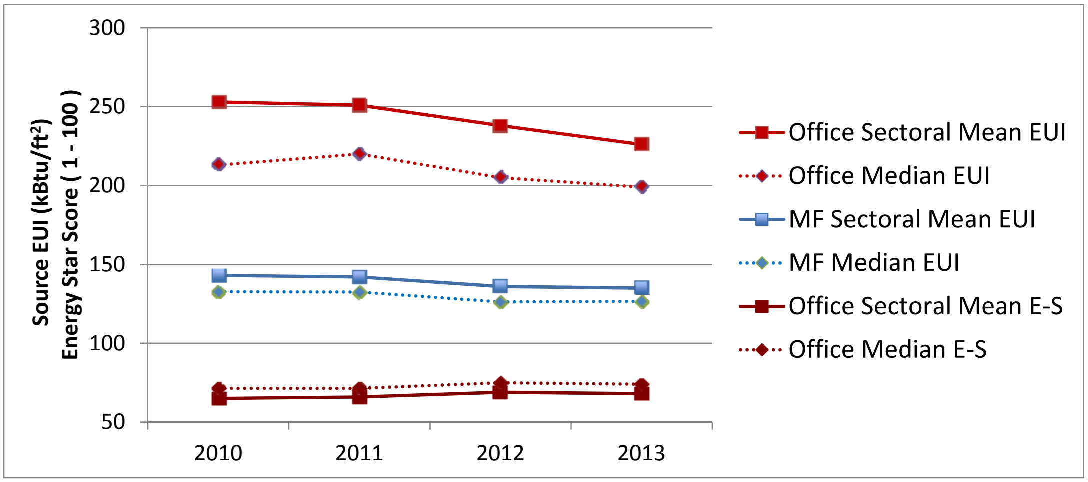

Figure 3: Sectoral weather normalized source EUIs and Energy Star scores, 2010 – 2013, for buildings reporting in all four years.

LL84 data also allows us to look at how buildings from different eras perform. The results for multifamily and office sectors are presented in Figure 4, and show a steady increase in EUI for office buildings if the data point for the ill-defined pre-1900 period is ignored. It will be interesting to see, as data for post-2010 buildings becomes available, whether the decline in the 2000s for office buildings represents a real change, perhaps a result of increased code stringency.

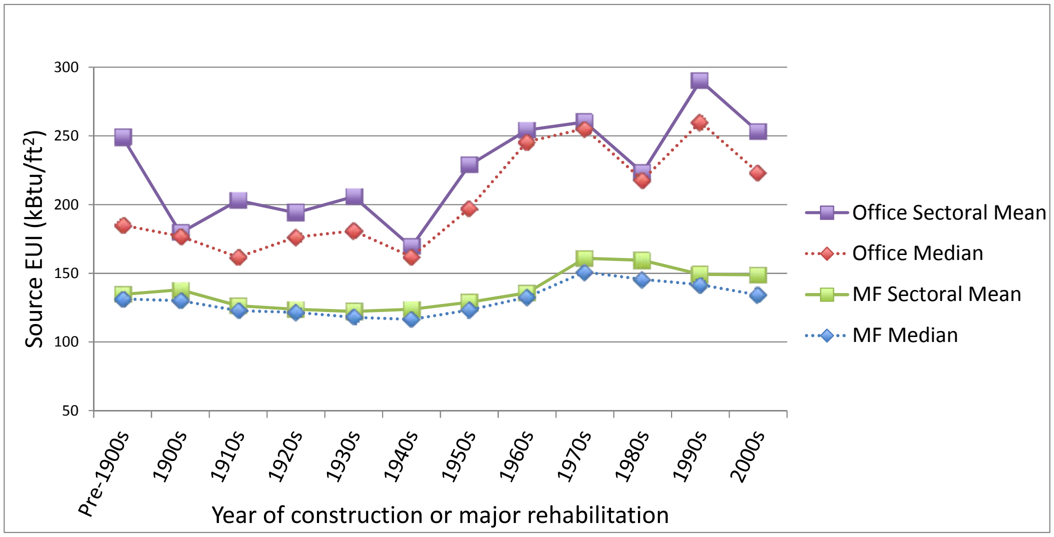

Figure 4: 2013 Source EUIs for Multifamily and Office sectors.

[4] There were no Energy Star scores for multifamily buildings in this period. For a discussion of the medians and sectoral means, see the Appendix on Data Treatment.

Envelope and Energy System Characteristics and Savings Opportunities in New York City's Large Buildings

This section presents the aspects of building characteristics gathered from LL87 filings, and where possible, points to potential energy or emissions reductions revealed by this data. Figure 5 shows that energy for heating and domestic hot water (DHW) dominate in multifamily buildings, while electric energy for cooling, lighting, and process loads constitutes the majority of the energy used in office buildings. The site energy data from the audits were converted to source energy to indicate the environmental impact clearly.

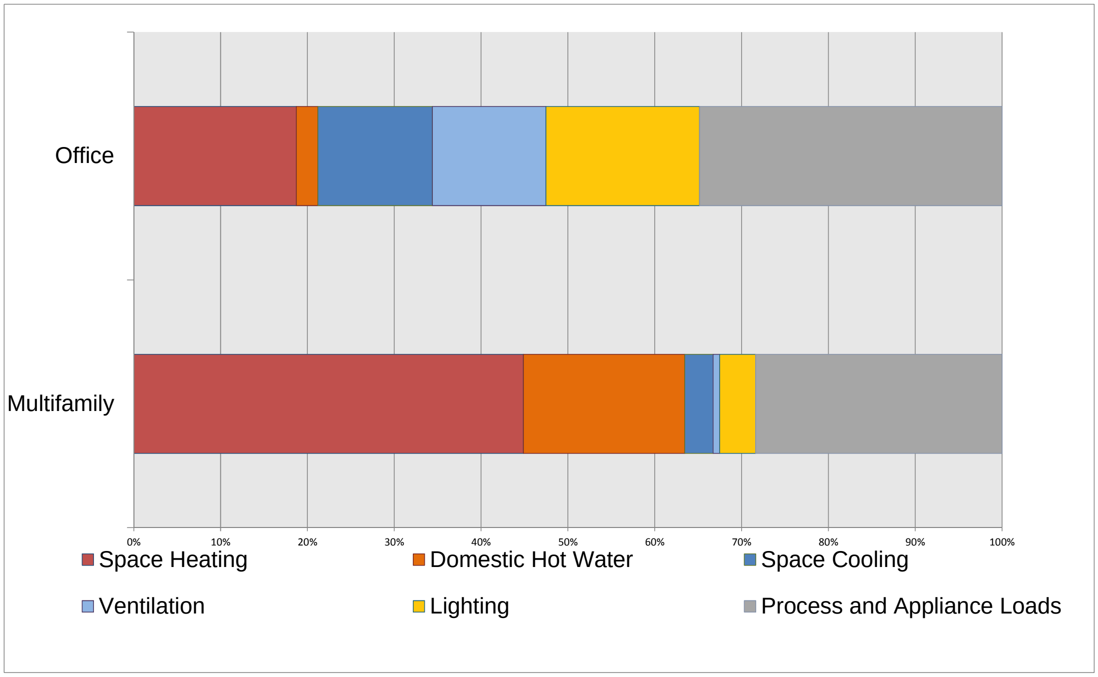

Figure 5: Source energy end-use breakdowns from office and multifamily audits

The next set of figures present the prevalence of various technologies or systems by reporting the fraction of audited floor area served by each. For lighting, each audit reported the area served by each different system within a building. For all other systems, the audits reported the total building area as if it were served by the single most widely-used system and these summaries are based on those areas. Clearly the reported fractions of floor areas served do not represent energy use with any precision, but they do indicate the level of implementation of the technologies. The sectors are reported as Office, Multifamily, and Other, and both Office and Multifamily are further disaggregated by size.

Figure 6 reveals the fractional areas served by various lighting technologies. The multifamily sector has the largest opportunity to save energy through lighting improvements, with 40 percent of the sector lit by low-efficiency T-12 fluorescent lamps and incandescents.[5] These low-efficiency lamps serve more than half the area of low-rise multifamily buildings. Almost 60 percent of the office sector is already using higher efficiency fluorescents, but there

[5] The low fraction of incandescent lighting in multifamily properties may indicate that many auditors did not include the apartments.

are still opportunities in high-rise and very large office buildings. LEDs have not yet achieved widespread deployment, although they have made inroads in every sector. High intensity discharge (HID) lamps are restricted to industrial or storage areas because of their brightness.

Data on lighting controls (chart not included; see NYC EER 2016) revealed that around 90 percent of audited floor area is served by lighting that is either manually controlled or on at all times. This constitutes a potentially large area for substantial electric savings, which will be exploited as a result of increased energy code stringency and the requirements of Local Law 88 of 2009,[6] if not voluntarily.

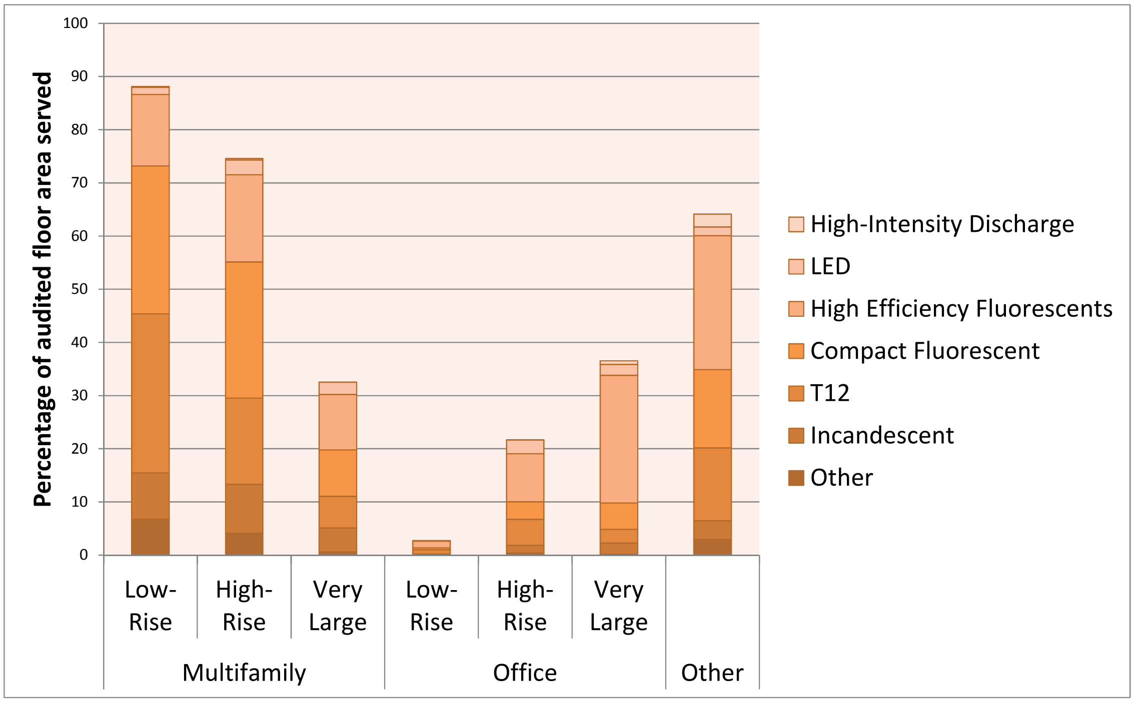

Figure 6: Fraction of floor area illuminated by lighting types, most efficient at top.

The data showed that almost 90% of multifamily buildings and 70% of all buildings rely on their space heating boiler to also provide domestic hot water using tankless coils or other heat exchangers. (Chart not included; see NYC EER 2016.) This means these buildings must operate their large heating system boilers even in the summer, when efficiency can be as low as 50%. Replacing these with high efficiency condensing boilers and storage tanks can lower fuel use and emissions substantially, although cost and payback must be determined for each building. This data indicates that 75% of the DHW supply in New York City is a candidate for such an upgrade.

The majority of New York City's buildings are of concrete and/or brick mass wall construction, as shown in Figure 7, providing substantial thermal mass. Steel frames, taken as curtain wall construction, are more common in very large residential and commercial buildings. The auditors did not have an option for the newer window-wall construction, which is poured concrete and glass. Because it resembles curtain wall, it may have been reported as steel-framed.

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[6] Local Law 88 if 2009 will require code-compliant lighting and submeters in all large buildings by 2025.

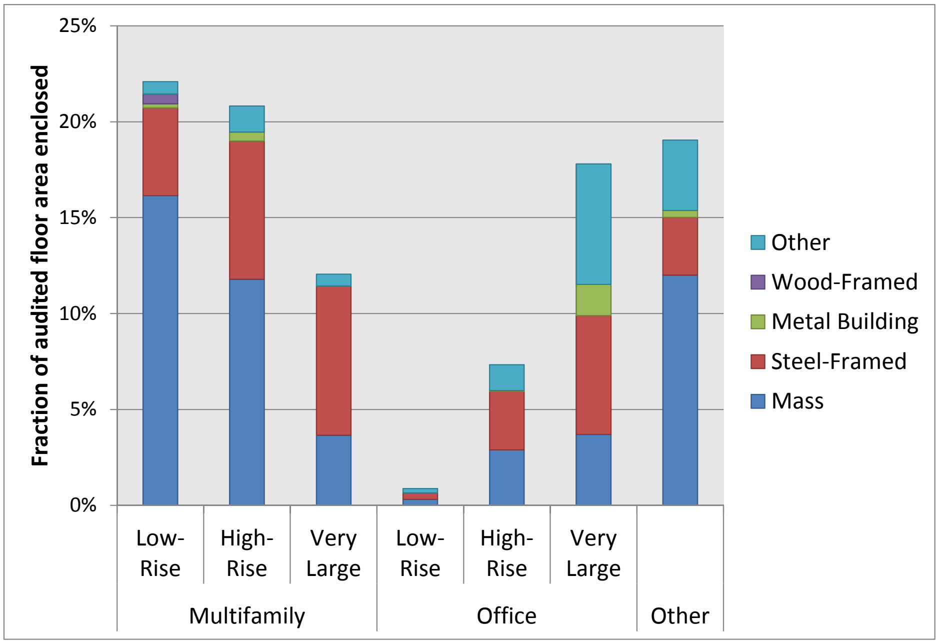

Figure 7: Fraction of floor area enclosed in various construction types.

Window glazing is an important aspect of a building's thermal integrity, and Figure 8 presents the first city-wide estimate of glazing fraction of which we are aware. Building window-to-wall ratios are well below the prescriptive code maximum of 40% (ASHRAE 2013) for all but very large office buildings. This stands in contrast to the high window-to-wall ratios typical of the curtain and window wall systems prevalent in new construction. The vast majority of NYC windows are double-pane with aluminum frames. The single pane glazing in office buildings reflects in part a group of mid-century modern high-rise buildings that can be difficult to retrofit with double pane curtain walls. "Other" glazing includes both residual storm windows and a small amount of triple glazing, usually installed for sound control in newer construction.

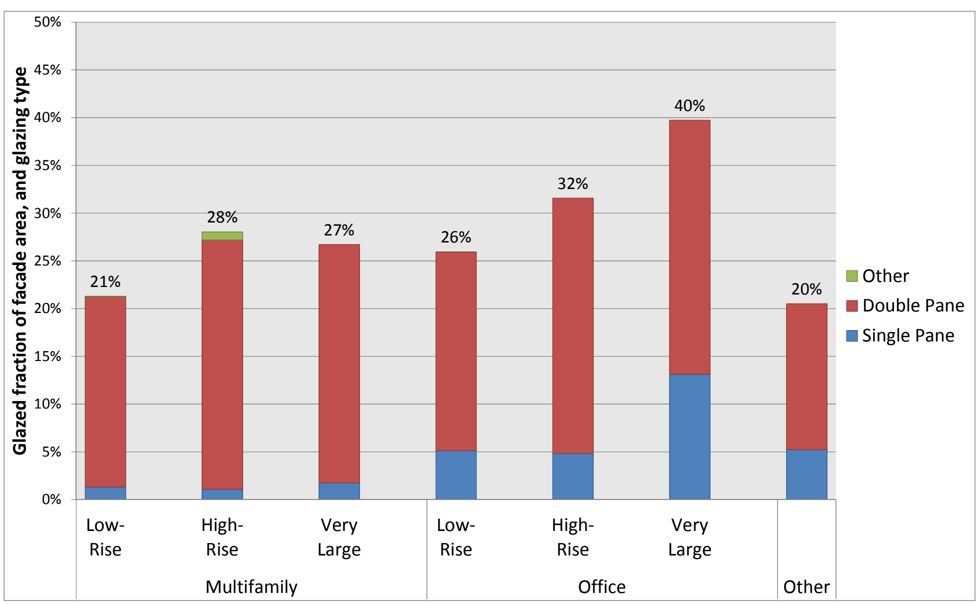

Figure 8: Sectoral mean fraction of vertical façade area glazed by three window types.

Windows conduct about five times more heat than walls, so buildings with greater window areas are expected to have increased heating and cooling loads (Wilson 2010). However, Figure 9 shows that for audited existing multifamily buildings with double glazing, fuel use was not strongly correlated with glazed fraction. Cooling energy was not included in this analysis. The green dots indicate buildings constructed since 1990. This data bears out common knowledge that other thermal loss mechanisms such as infiltration are important in today's buildings. Because of the implications for code design and the contrast with the predictions of models, further study using more LL87 data or data from other cities to explore cooling energy use and other factors such as age or effective energy code at time of construction, would be helpful.

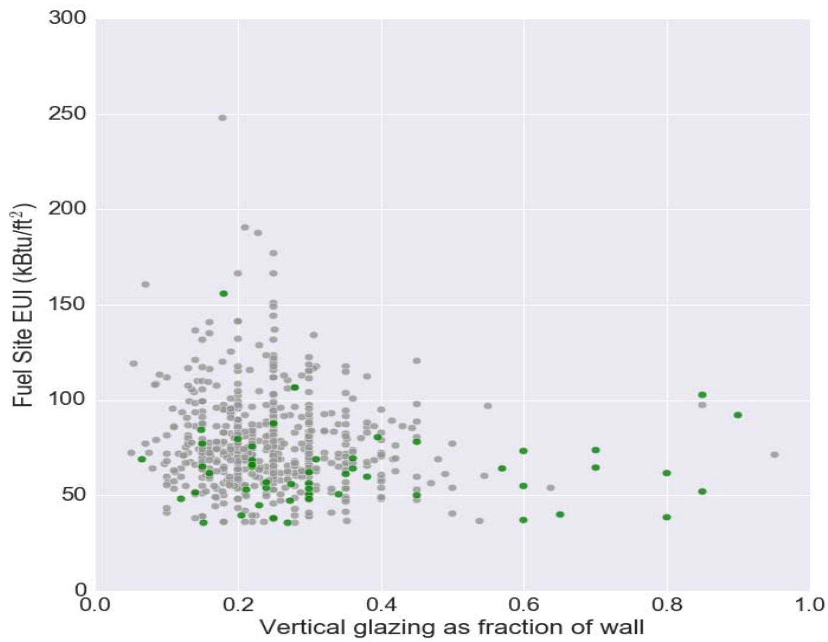

Figure 9: Heating fuel-only site EUI as a function of window-to-wall ratio in double-glazed multifamily buildings.

For space heating, steam distribution dominates in NYC, covering three quarters of the floor area. (Charts not included here.) These can be fed from a boiler in the building or through Con Edison's district steam system. Hydronic systems are commonly fed by a hot water boiler, but can also use a heat exchanger connected to a steam boiler or a district steam loop. Forced air and electric resistance heating supply only 5 and 2 percent of the audited floor area, respectively.

One-pipe steam systems are prevalent in multifamily buildings, supplying 27 percent of audited area. A single pipe carries steam to and condensate from the radiator. Two-pipe systems have separate lines to supply steam and return condensate, are easier to control, and are generally quieter and more comfortable for residents. They supply 33 percent of audited area. A vacuum steam system is a 2-pipe system with the addition of a vacuum pump, which allows even greater efficiency and control, and these systems supply 13 percent of audited area. Hydronic systems have two pipes, supply and return, circulating hot water through the radiators, supplying heat to 19 percent of audited area.

Based on a study of the 260 audited properties with data useful to this purpose and as shown in Figure 10, multifamily buildings using one-pipe steam consume 30% more energy than the other principal heating systems. The results are displayed in a "violin plot," in which the width of the figure indicates the relative number of properties at that EUI within each system type. The long upper tail on the distribution found for one-pipe steam systems, indicates a number of very poorly run systems.. The compact shape of the plot for vacuum steam is consistent with the service contracts and high-quality maintenance associated with these systems.

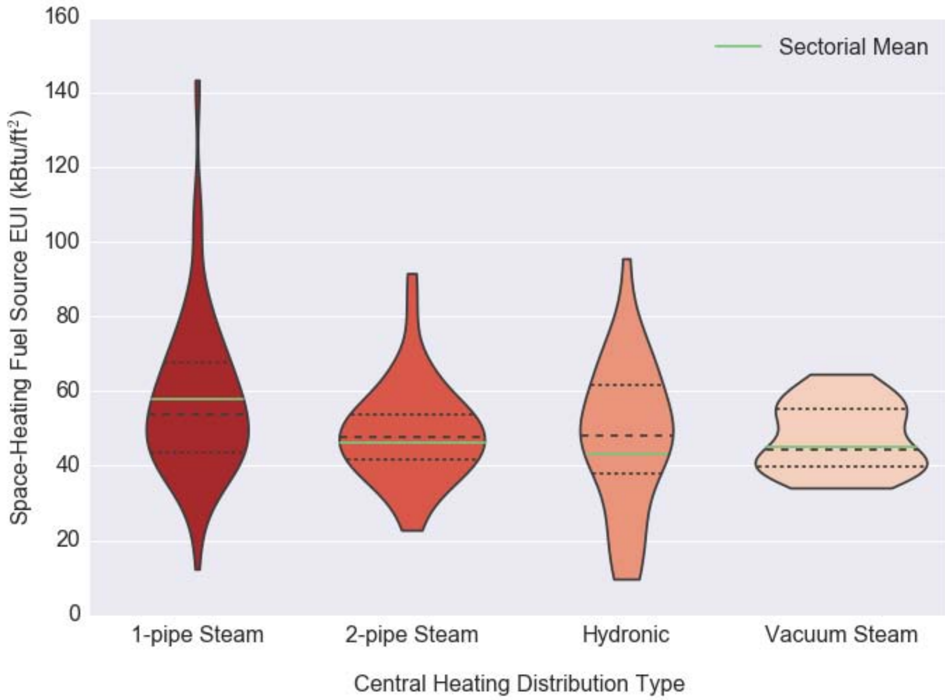

Figure 10: Distribution (number) of properties versus source EUI based only on heating fuel. Green line shows the sectoral EUI for each system type, dotted lines show median and quartiles.

Energy and Emissions Reduction Opportunities Found by LL87 Energy Audits in New York City's Large Buildings

The energy audits carried out by engineering firms for building owners under LL87 proposed a wide range of ECMs with varying energy reduction potentials and economic attractiveness. The individual audit reports presented guidance for each building, but the results reported here summarize proposals for many different ECMs in different buildings, and should be used only to get a broad sense of citywide findings. For actual buildings, individual assessments and savings projections are needed to guide investments. Figure 11 summarizes these results by showing both which types of proposed energy conservation measures (ECMs) were most popular with auditors (shown higher in the chart), and the median expected savings for each type of ECM, in buildings for which an ECM of that type was recommended. (Only ECMs recommended in over 100 properties are included.)

These projected savings work out to only a few percent of annual usage (NYC EER 2016), and many knowledgeable observers are surprised that projected energy reductions were not greater. The recommendations are consistent with each other in intensity and estimates of economic viability, but fall short of both estimates and reported measured savings found in other studies (Deutsche Bank 2012, McKinsey 2009), including a NYSERDA study (Falk and Robbins 2010) that observed average reductions of 19.7% over seventeen retrofitted buildings. One reason for this may lie in the very low current price of natural gas. Results on payback analysis (NYC EER 2016), found many cost-effective measures that reduced electricity use, but only four areas (distribution systems, domestic hot water, HVAC controls, and heating systems) with ECMs that could pay for themselves with gas savings.

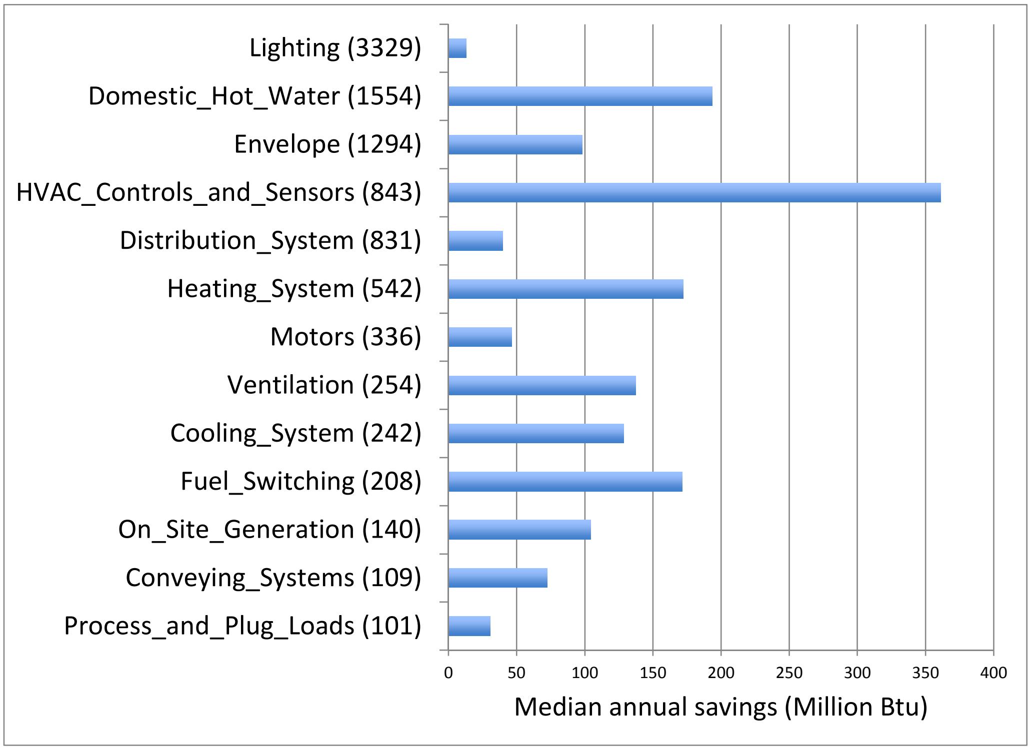

Figure 11: Median expected energy savings per building for each ECM category. The number of ECMs proposed in each category is in parentheses.

Conclusions and Recommendations

For the fourth year, New York City has collected the largest set of energy and water use data in privately owned building in the world, covering almost half of its total floor area. This year, for the first time, it has collected detailed system information on characteristics of and technologies used by individual buildings, allowing a new understanding of how a city's building stock uses energy. This data shows there is a universe of measures that can be taken to improve the energy efficiency of the city's buildings, many of which were summarized above. Based on experience working with this data, we offer a few proposals for any agency considering undertaking or expanding similar efforts:

1. Improve the data collection process:

a. Audit and RCx data collection forms should be as simple and clear as possible. Systems should be included in the forms in a way that will rule out impossible technology combinations based on fuel types and end uses.

b. Accurate floor area: Many property floor areas differ by more than 10% and sometimes over 30% between data sources. Correct floor areas are vital for accurate EUIs, so validation of floor area data should be required, perhaps by a design professional.

c. The low quality of some benchmarking reports indicates that cities should provide training and consider requiring certification for benchmarking consultants. Consultants who currently submit LL87 audits in NYC must have a professional credential, and Chicago's benchmarking program requires data to be certified by a design professional every three years.

d. Public Service commissions should require utilities to provide automatic uploading of whole-building energy data.

2. Increase impact and usability of data:

a. Utilize sectoral EUIs (area-weighted means) when comparing the energy performance of sectors or classes of buildings. Utilize medians and quartiles to allow building owners to assess the relative performance of their building.

b. Data cleaning and analysis approaches should be coordinated with national efforts, such as the U.S. DOE's Standard Energy Efficiency Data Platform (SEED 2016).

c. Much more data should be made public than is now the case, appropriately anonymized, perhaps using techniques developed by the US Census Bureau.

d. Include enough information on building geometry to allow DOE's Asset Rating Tool (EERE 2016) to generate an Asset Score from the audit data.

e. Facilitate the transfer of building-level data to government and utility incentive and financing programs.

3. Expand reporting requirements:

a. As benchmarking, audit, and retrocommissioning programs mature, they should be extended to more buildings. In NYC, lowering the threshold to 25,000 square feet would add roughly 10,000 properties to the set, covering almost 60% of the gross floor area.

Appendix on Building Populations

Buildings reporting in 2013 fell into one of many self-selected categories: multifamily, office, and a large number of more specialized sectors grouped together here as "other." The "other" categories include schools and hospitals, while the largest "other" categories are non-refrigerated warehouses and senior care centers. The "other" categories are listed in NYC EER 2016. Multifamily properties comprise 67% of NYC's floor area, followed by office properties at 24%.

The 13,000 non-municipal properties covered by LL84 are only 2% of the city's buildings, but comprise 2.3 billion square feet of floor area, about 42% of the total area in the city. Most benchmarked multifamily and office properties follow similar historical construction trends with both sectors booming in the 1920s, 1950s-60s, and 2000s, with the largest buildings constructed in the 1970s in both sectors. Finally, 25% of multifamily buildings had retail, a bank, or similar mixed use on lower floors, while 60% of office buildings had more than one tenant. City-owned properties over 10,000 square feet are also required to benchmark annually, bringing the total coverage of Local Law 84 to almost 50% of the city's floor area. City-owned properties were not included in this analysis.

Appendix on Data Quality and Treatment

The final LL84 and LL87 datasets used for this analysis are products of several stages of cleaning processes to remove outliers and entries with errors or missing information. All entries that did not report or misreported identifying information, such as the Borough, Block, and Lot

(BBL) number, duplicates, and dissimilar entries with the same identifier were removed. Properties whose reported floor area differed from the public city record (PLUTO 2015) by 30% or more were also dropped. Then entries with EUIs outside lower and upper cutoffs based on habitability (50 kBtu/sf and 1,000 kBtu/sf) were removed, except that the lower limit did not apply to expected low-energy users like warehouses. These steps left 8,995 entries for source energy use analyses and 7,590 entries for weather normalized source energy use analyses.

The cleaning process for LL87 included the same steps, but then flagged dubious data, allowing the flexibility of including properties for queries where they had good data even if other data was not useful. Properties in both LL84 and LL87 data sets were discarded if their floor areas did not agree within 10%. This resulted in a total of 1,123 entries, around half the number of entries found in the cleaned LL87 2013-2014 dataset by itself.

Compliance with LL84 and LL87 is an important issue. The standard measure of compliance asks whether a property owner submitted a report. A more useful metric would be based on submission of a report with energy information meeting the criteria above. For example, while 90% of multifamily building owners submitted a report, only 78% submitted a report with energy information that could be used for analysis. The NYC Department of Buildings is taking steps to address data quality, and as of 2016 will review benchmarking submissions for completeness and accuracy before the data is accepted as compliant.

Appendix on Methods: Sectoral EUIs, Area-Weighted Means, and Medians

Most reports on benchmarked data from cities have reported building performance by presenting data on the median EUIs of buildings city-wide or in various sectors or classes of interest. The median and similar data on quartiles or other descriptors of the distribution of EUIs is very useful when comparing the performance of individual buildings to their peers, but it is less useful when comparing the performance of one or more sectors or classes of buildings. The problem is that the median does not take into account the differing sizes of buildings. To compare one group of buildings to another, say multifamily buildings to office buildings, one needs the sectoral EUIs of each group, that is:

$$EUI_{(Sectoral)} = (\text{Energy consumed in sector})/(\text{Floor area of sector})$$

This can be calculated as totals of the benchmarking data, but often it is more convenient to work from EUIs that have already been calculated for individual buildings. NYC's procedures, for example, use Portfolio Manager to generate weather-normalized EUIs for each building, so direct use of these values is convenient. The sectoral EUI as defined above can also be expressed exactly as:

$$EUI_{(Sectoral)} = (\Sigma\ A_i * EUI_i)/(\Sigma\ A_i),$$

Where the sum on "i" is over all properties in the group, sector or class of buildings, and constitutes an area-weighted mean of the individual EUIs. The sectoral EUI is used for groups of buildings by the US Energy Information Administration in RECS and CBECS,[7] and has been previously utilized in studies of New York City benchmarking results. (Scofield 2013).

The importance of using sectoral EUIs can be seen in Figure 3, comparing the EUIs of the entire multifamily sector and the entire office sector. The sectoral EUIs represent all the energy used in the sector, divided by the floor area of the sector. This data is for properties reporting in all four years, so multiplying these sectoral EUIs by the total area of those properties would give the energy used by that set of buildings. On the other hand, if you use the medians for this purpose, you will underestimate the energy use of the Office sector by 12-15%, and of the MF sector by 6 – 7%.

The concern is sometimes raised that large buildings can dominate the sectoral EUI in such a way as to make it not representative of the bulk of buildings in a group. If one is assessing total energy use in the group, this critique is wrong – the energy use includes that of the larger buildings, and they cannot be ignored. If one is assessing how an individual building compares to its peers, then the use of the median or quartiles is appropriate.

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[7] "**Energy Intensity:** The ratio of consumption to unit of measurement (floorspace, number of workers, etc.). Energy intensity is usually given on an aggregate basis, as the ratio of the total consumption for a set of buildings to the total floorspace in those buildings." (EIA 2012)

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