

Towards an Equitable Grid-Interactive Efficient Building Landscape: Analyzing Technology Adoption in the State of New York

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ABSTRACT

Residential buildings are seeing an increase in technology adoption from smart thermostats and HVAC systems to distributed generation and battery storage. These technologies are making buildings more energy efficient and increasing the flexibility in how and when they consume electricity. The sum of these technologies is leading the sector towards grid-interactive efficient buildings (GEBs), which implement demand side management strategies to provide grid services while minimizing electricity costs and maximizing occupant preferences. As GEB technologies transform the current building stock into flexible grid assets, it is critical to understand where technology adoption occurs and the affordances it brings if the transition is going to be equitable and just. By visualizing the adoption of building technologies in residential buildings in the State of New York, this study seeks to understand the existing distribution of GEB technologies, the grid services they provide, and the communities that benefit from them. To do so, the technologies are traced to demand side management strategies and are mapped against socioeconomic data to assess which communities have seen the greatest adoption of GEB technologies. The extent to which homes have adopted GEB technologies are presented by economic development region (EDR) and cross-examined with income and education levels. The findings show that energy efficient technologies are more prevalent in homes across EDRs than technologies capable of shedding or shifting load. However, limited trends were identified when viewed across socioeconomic attributes. The tenets of energy justice are offered as a framework for disseminating the benefits of GEB technologies as adoption continues.

Introduction

Grid-interactive efficient buildings (GEBs) rely on a range of technologies to become smart, efficient, connected, and flexible. Without a prescribed set of technologies to achieve these characteristics, however, the combinations of technologies within a GEB can vary and the degree to which a building achieves these characteristics can differ. Through the adoption of GEB technologies, buildings and their occupants can engage in demand side management (DSM) strategies—namely, energy efficiency, load shedding, load shifting, modulation, and generation—to co-optimize for energy costs, grid services, and occupant preferences (Neukomm, Nubbe, and Fares 2019; Steen and Krarti 2020). By serving both the electric grid and building occupants by design, GEBs and their future landscape in the residential building stock must be considered both in the role they can play in a low-carbon electric grid as well as in a future energy system that is equitable and just.

Research has begun to quantify the technical potential of the building stock to serve as a grid asset in the United States and analyze the degree to which energy efficiency and flexibility, created from load shedding and shifting, can provide benefits to the grid and building occupants. One study suggests that energy efficiency and flexibility in the building stock could avoid up to

742 TWh of annual electricity use and 181 GW of daily peak net load in 2030, increasing to 800 TWh and 208 GW, respectively, by 2050 (Langevin et al. 2021). Analytical frameworks for quantifying the value generated by single-family, residential GEBs have been analyzed (Shah et al. 2020) and cost-optimal technology selection has been evaluated to improve end-user economics in homes with GEB technologies (O'Shaughnessy et al. 2018). These studies show the vast potential for GEBs in the residential sector to generate value to both the electric grid and the people who occupy those homes.

To reach this potential and realize value in practice, however, will require a massive transformation in the residential building stock with unprecedented investment in technology adoption. To date, the adoption of many distributed energy resources and GEB technologies has not been equitable. Inequities in rooftop solar PV adoption exist at a myriad of levels in the United States, albeit to varying degrees, with adopters often having relatively higher incomes and identifying as Non-Hispanic White (Darghouth et al. 2022; Barbose et al. 2022). Studies show that African-American households are less energy efficient than Caucasian households in the United State (Goldstein, Reames, and Newell 2022), and cross-country analyses indicate that families with young children and higher levels of education adopt more energy efficient technologies than households with a higher share of elderly household members (Mills and Schleich 2012). These patterns of technology adoption contribute to the systemic patterns of inequity seen in the affordability of energy costs in the United States, where low-income households; Black, Hispanic, and Native American households; renters; and older adult households have disproportionately higher energy burdens (i.e., the percentage of household income spent on energy bills) than the national median (Drehobl, Ross, and Ayala 2020).

As such, the call for energy efficiency and weatherization (i.e., improvements to a building to protect it from the elements and increase energy efficiency) assistance to overcome these inequities are increasing (Lewis, Hernández, and Geronimus 2020), local initiatives to raise energy efficiency levels in low-income communities are growing (Harmon et al. 2020), and efforts to promote more equitable energy efficiency policies are gaining traction (Drehobl 2021). The existing body of literature shows the need to rectify inequities in technology adoption and to develop policies that enable more just outcomes in the future. While much work has focused on energy efficiency and customer-sited generation, there is a need to consider GEB technologies that can engage in other DSM strategies. If GEBs are to contribute to both a clean and just energy future, we must understand now where technology adoption has occurred and who is benefiting to ensure the future landscape of GEBs is not limited to a narrow segment of society.

To that end, this paper analyzes GEB technology adoption in the residential building sector in the State of New York, maps those technologies to the DSM strategies they enable, and visualizes the communities that are currently benefitting the most from them. In doing so, we provide a method for thinking across technologies and communities to support the full realm of benefits that GEBs can provide in the residential building stock. The data and methods used to do so are explained in the section that follows.

Data and Methods

In 2019, the New York State Energy Research and Development Authority (NYSERDA) conducted an assessment of single-family residential buildings (i.e., residential structures containing one to four living units) (Cadmus Group 2019). In their assessment, they surveyed 2,419 individuals about the condition of their home, the technologies within those homes, and existing perceptions on energy efficiency through phone and web surveys across the ten

economic development regions (EDRs) (see Figure 1). An EDR comprises several counties and shares a long-term plan for economic development (EDC n.d.; Empire State Development n.d.). The survey created the most comprehensive representation of technology adoption in single-family homes in the state. More detailed information collected from onsite visits, such as thermostat setpoints, supplemented the survey data, but the work conducted herein relies solely on the survey data given its more extensive coverage and collection of socioeconomic attributes. This work evaluates several of the technologies at an EDR level to provide more granular insights into adoption trends and analyze those trends in combination with the socioeconomic attributes that were reported in the survey. This builds upon previous work that presented technology adoption results at the state and climate zone level without consideration to the socioeconomic data (Cadmus Group 2019).



Figure 1. Economic development regions in New York.

To ensure the results were representative of the population within the EDR in which they were sampled, conditions for inference on the proportion of the adopted technologies were checked, and only technologies that met those conditions (i.e., the sample was random, approximately normal, and relied on independent sampling) and had a confidence interval of 90% +/- 15% were included in the analysis. Ultimately, eleven technologies were considered out of over 25 that were tracked. Clothes washers and home energy management systems were among the technologies unable to meet conditions for inference. Other noteworthy technologies such as batteries, electric vehicles, and solar photovoltaic systems were not tracked in the dataset. For a complete list of technologies tracked within the single-family residential building assessment, the reader is referred to the full survey report (Cadmus Group 2019). The selected technologies were then mapped to the DSM strategies they afford (see Table 1).

As a DSM strategy, energy efficiency is considered the overall, persistent reduction in load; shedding is the reduction of load over either short or long durations; and shifting is the action of changing the time at which energy is consumed to align with off-peak periods of demand for the utility or to align with excess renewable energy generation (Nubbe and Yamada 2019). Technologies such as TVs, refrigerators, desktop computers, laptop computers, and lightbulbs can engage in energy efficiency through technology design, minimizing energy waste

and reducing consumption from the device. These technologies can be compared to smart lights and occupancy sensors that decrease overall consumption through changes in usage and automated energy behaviors. Smart lights and smart thermostats can respond to demand response signals to shed load, and they can be programmed to shed load under defined scenarios. Similarly, smart thermostats and smart water heaters can be programmed to shift their loads in response to price signals or other customer preferences. Note that both smart thermostats and remote-controlled thermostats are considered in this study. While nearly all smart thermostats can be controlled remotely, not all remote-controlled thermostats are smart (i.e., smart thermostats use learned or detected information to change operations and can be controlled remotely, but not all remote-controlled thermostats have intelligent capabilities). If a smart thermostat was reported in a survey response, it was also deemed capable of remote control even if it had not been reported as such. The eleven technologies considered in this study are first visualized by the ratio of their adoption in each EDR and the DSM strategies in which they can engage. The technologies are then aggregated based on their associated DSM strategies.

Table 1. Building technologies mapped to the demand side management strategies they enable.

Demand side management strategy	Technology
Energy efficiency	TV, refrigerator, desktop computer, laptop computer, lightbulbs, smart lights, occupancy sensors
Shedding	Smart lights, smart thermostat, remote-controlled thermostat
Shifting	Smart thermostat, remote-controlled thermostat, remote-controlled water heater

Based on the survey responses, the energy efficiency of a home was in part measured by the number of ENERGY STAR-rated appliances—TV, refrigerator, desktop computer, and laptop computer—it was reported to have. ENERGY STAR is a government-backed rating system that indicates compliance to federally mandated energy efficiency guidelines (ENERGY STAR n.d.). Any non-rated appliances that were reported still contributed to our sample size, but they had no impact on the household’s efficiency performance. A home was considered to have energy efficient lightbulbs if it was reported to have either light-emitting diode (LED) or compact fluorescent rather than incandescent bulbs. If any of the remaining technologies (i.e., smart lights, occupancy sensors, smart thermostats, remote thermostat, or remote-controlled water heaters) were reported, they were deemed capable of providing the DSM strategy they are mapped to in Table 1. Any survey response that did not have an answer for a given technology, preferred not to answer, or did not know was excluded for that category. With the exception of the appliances that had ENERGY STAR ratings and light bulbs, which mapped to energy efficiency, the remaining DSM strategies were assigned based on a technology having a medium or high capability of engaging in the strategy (Goetzler, Guernsey, and Kassuga 2019; Nubbe and Yamada 2019).

For each survey respondent, an aggregate rating of low, medium, or high was assigned based on the percentage of technologies reported in each DSM strategy category (Table 2). For example, if a survey respondent provided answers for four technologies that could provide energy efficiency and three of those technologies were ENERGY STAR-rated, they would have an aggregate percentage of 75% for energy efficient technologies, translating to a high rating.

The ratings for shedding and shifting technologies are more constricted given the limited number of technologies considered within those categories. For example, if a survey respondent provided responses for all three shedding technologies and reported having smart lights and a remote-controlled thermostat, but the thermostat was not smart, they would have a shedding rating of approximately 67% or medium.

Table 2. Aggregate DSM categorization.

Percentage of technologies adopted in DSM category	Rating
0-34%	Low
35-67%	Medium
68-100%	High

For each survey respondent that had a DSM rating assigned to it, two socioeconomic attributes were considered: income and education level. Survey respondents could select from a range of predefined responses for the respective attributes. The possible responses for both education and income level informed the rating categorizations used in Table 3. If a survey respondent elected not to provide an answer for a socioeconomic attribute, they were excluded from this portion of our analysis and not represented in the subsequent visualizations. The results of this analysis are presented in the section that follows.

Table 3. Socioeconomic attributes categorization.

Socioeconomic attribute	Rating	Definition
Education	High school	Highest level of education in the household was up through some high school education
	College	Highest level of education was up through some college education; completion of degree not required
	Graduate	Highest level of education was up through some graduate education; completion of degree not required
Income	Low	Less than \$50,000
	Medium	At least \$50,000, less than \$100,000
	High	\$100,000 and above

Results

The percentage of respondents in each EDR reporting a given technology in their home was first calculated. Figure 2 depicts these percentages and maps the technologies to the DSM strategies they enable, showing that little variation exists in technology adoption across EDRs. That is to say, the extent to which the population in one EDR has adopted a technology is often similar to that of the other EDRs. Moreover, almost all respondents who reported having a TV in their home reported them to be ENERGY STAR-rated. Energy efficient lightbulbs and ENERGY-STAR refrigerators are also common with roughly 75% of the population in each EDR, or more, having these technologies within their homes. Occupancy sensors contribute to homes' energy efficiency to a lesser degree, with around a 25% adoption rate, and smart lights have yet to make substantial contributions to energy efficiency in homes. This suggests that

energy efficiency is often generated through the adoption of more efficient technologies rather than the adoption of technologies designed to manage energy consumption through automated behavioral changes. Smart lights, smart thermostats, remote-controlled thermostats, and remote-controlled water heaters have, in comparison, seen limited adoption, thus limiting the existing opportunities for the residential building stock to engage in shedding and shifting. Adoption of remote-controlled water heaters is notably low. Across EDRs in New York, energy efficient technologies have been adopted more than the technologies considered in the shedding and shifting categories. While many factors can affect technology adoption, these differences could be attributed to ENERGY STAR's well-known and long history of certifying energy efficient technologies, the cost and associated payback period of purchasing different technologies, or even the utility rate structures to which many residential customers are subject; flat rate structures, for example, promote an overall reduction in consumption rather than incentivizing customers to shed or shift their load like time of use rates do.

These technologies were then categorized based on their DSM rating and cross-examined with the socioeconomic attribute ratings. Figure 3 illustrates that most respondents have achieved a low or medium ranking for energy efficiency across EDRs, likely unable to surpass the threshold to high given the limited adoption of occupancy sensors and smart lights in that category. Those with a medium energy efficiency rating often report having medium and high incomes. However, the general trend of a medium or low energy efficiency rating being prevalent persists in most homes categorized as low income, too. North Country and Western New York reported a more even distribution of efficiency levels across income classes for low and medium efficiency ratings when compared to other EDRs. With respect to education level, few survey respondents report having only a high school education. Most EDRs are dominated by respondents who reported a medium or low level of energy efficiency and either some college or graduate education.

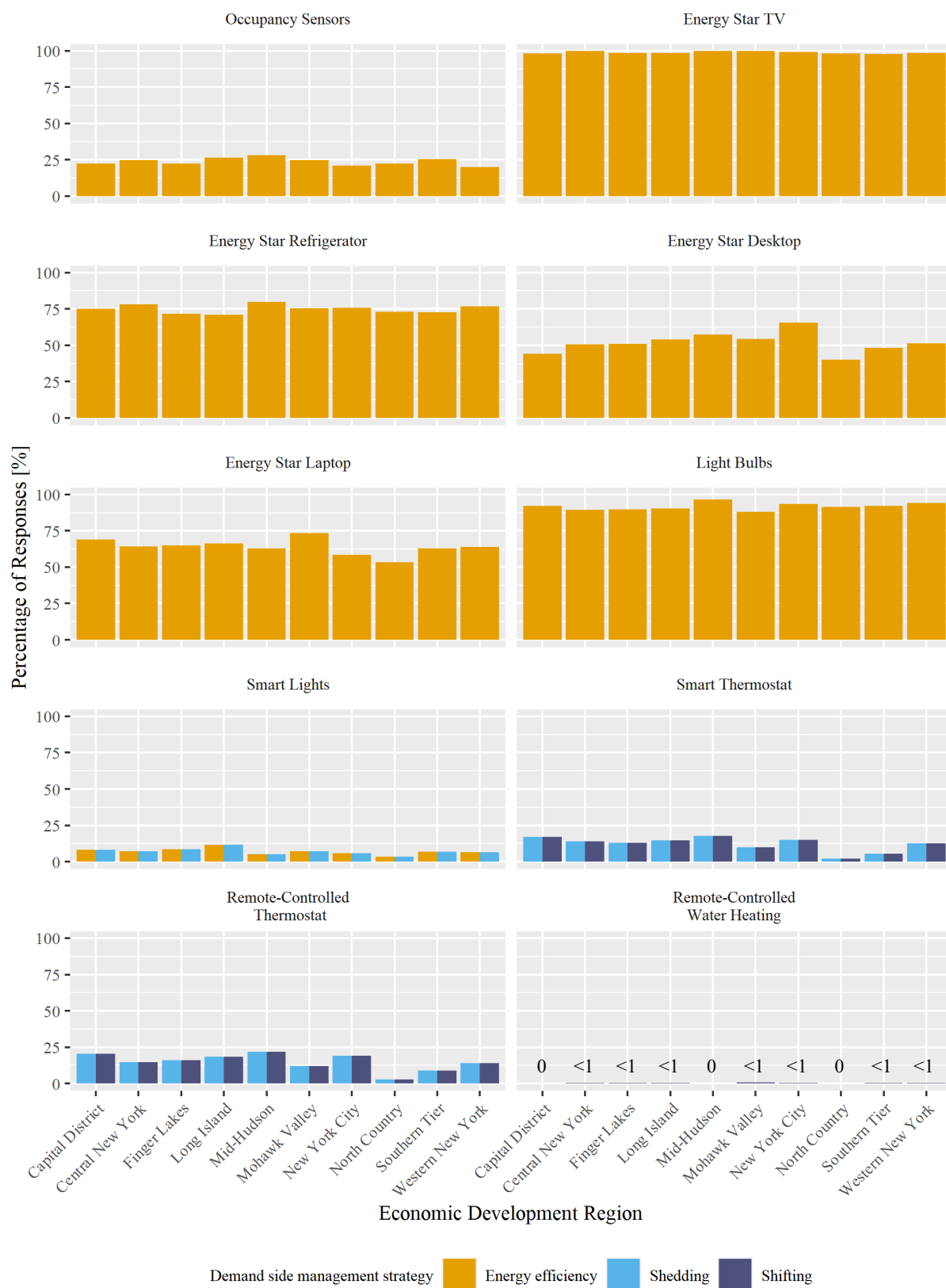


Figure 2. Technologies adopted in each EDR in New York.

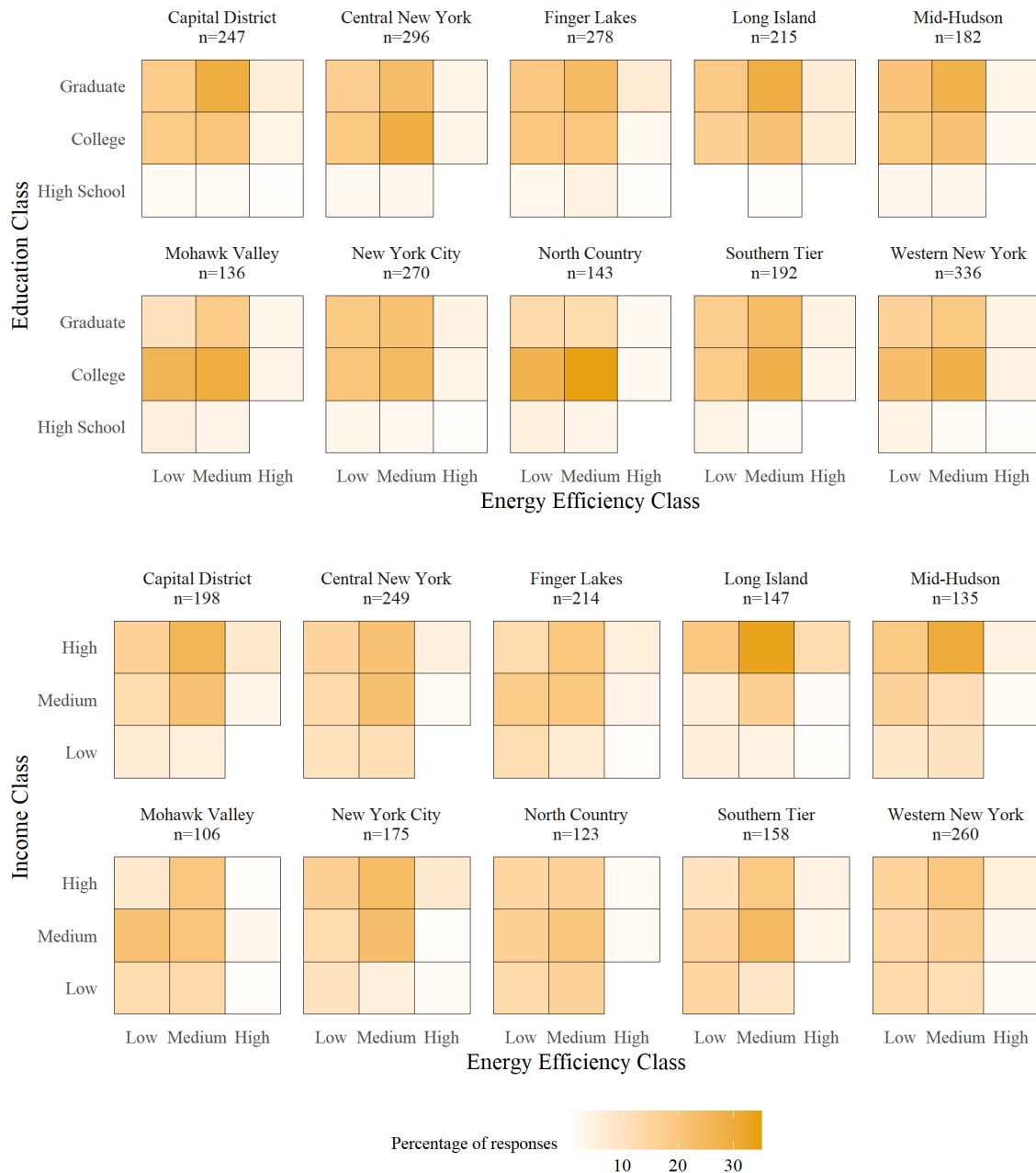


Figure 3. Energy efficiency categorization and socioeconomic attribute heatmaps. Missing tiles indicate no responses were available.

Compared to energy efficiency, EDRs across New York have achieved a lower level of capability from shedding technologies. Regardless of income or education, low levels of shedding capabilities persist (see Figure 4). Many EDRs lack any survey responses that report both high levels of shedding technologies in the home and a low income or high school education. Thus, although adoption of shedding technologies remains limited, when a survey respondent does have a high rating, it is unlikely for that respondent to also report a low income or high school education.

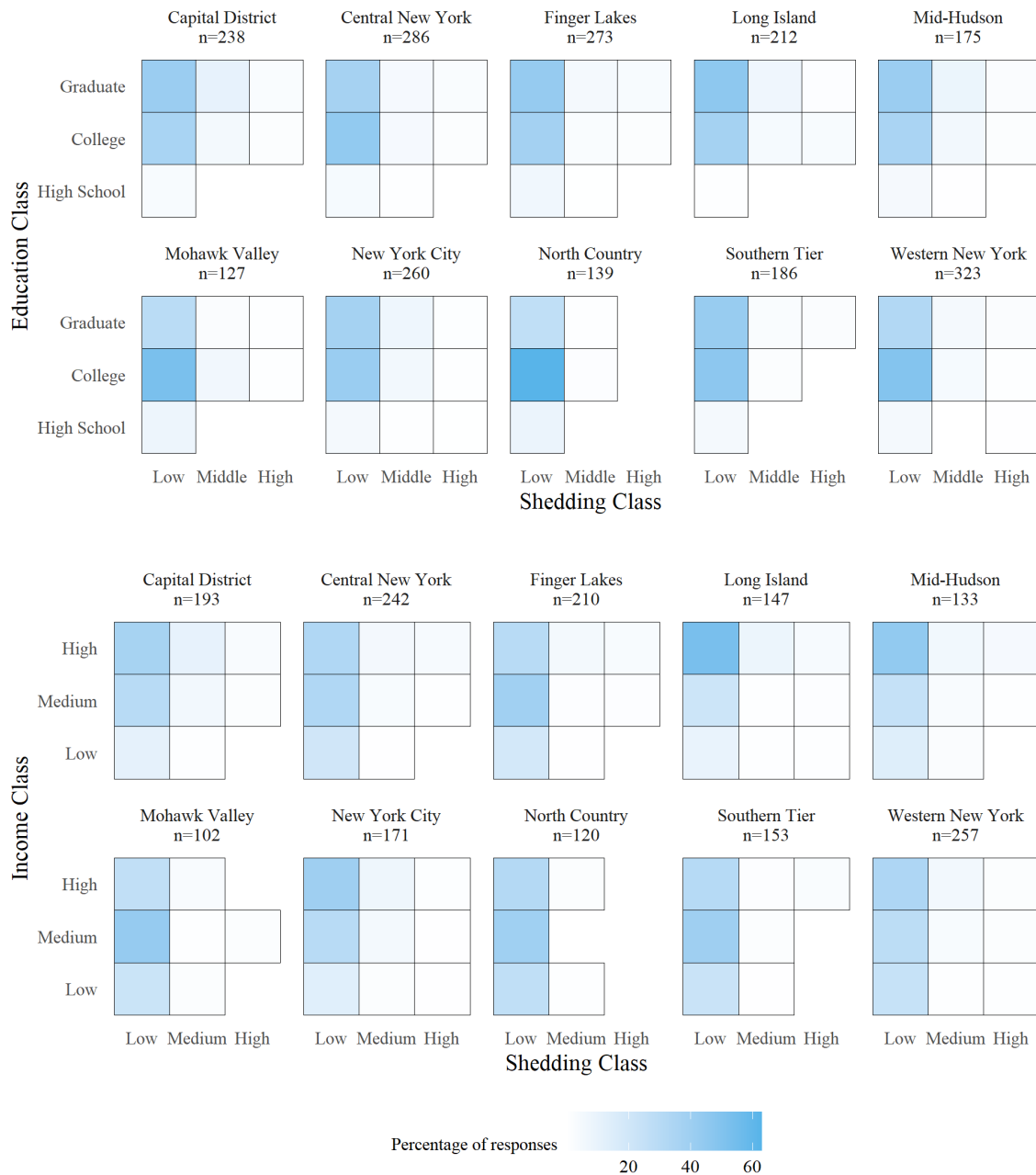


Figure 4 Shedd categorization and socioeconomic attribute heatmaps. Missing tiles indicate no responses were available.

Similarly, few shifting-capable technologies have been adopted across EDRs in New York. Most households report low levels of shifting technologies across income classes and levels of education (see Figure 5). Few EDRs have any responses with high shifting capabilities. A discussion of these results and the broader implications of disseminating the benefits of GEB technology deployment at scale follows.

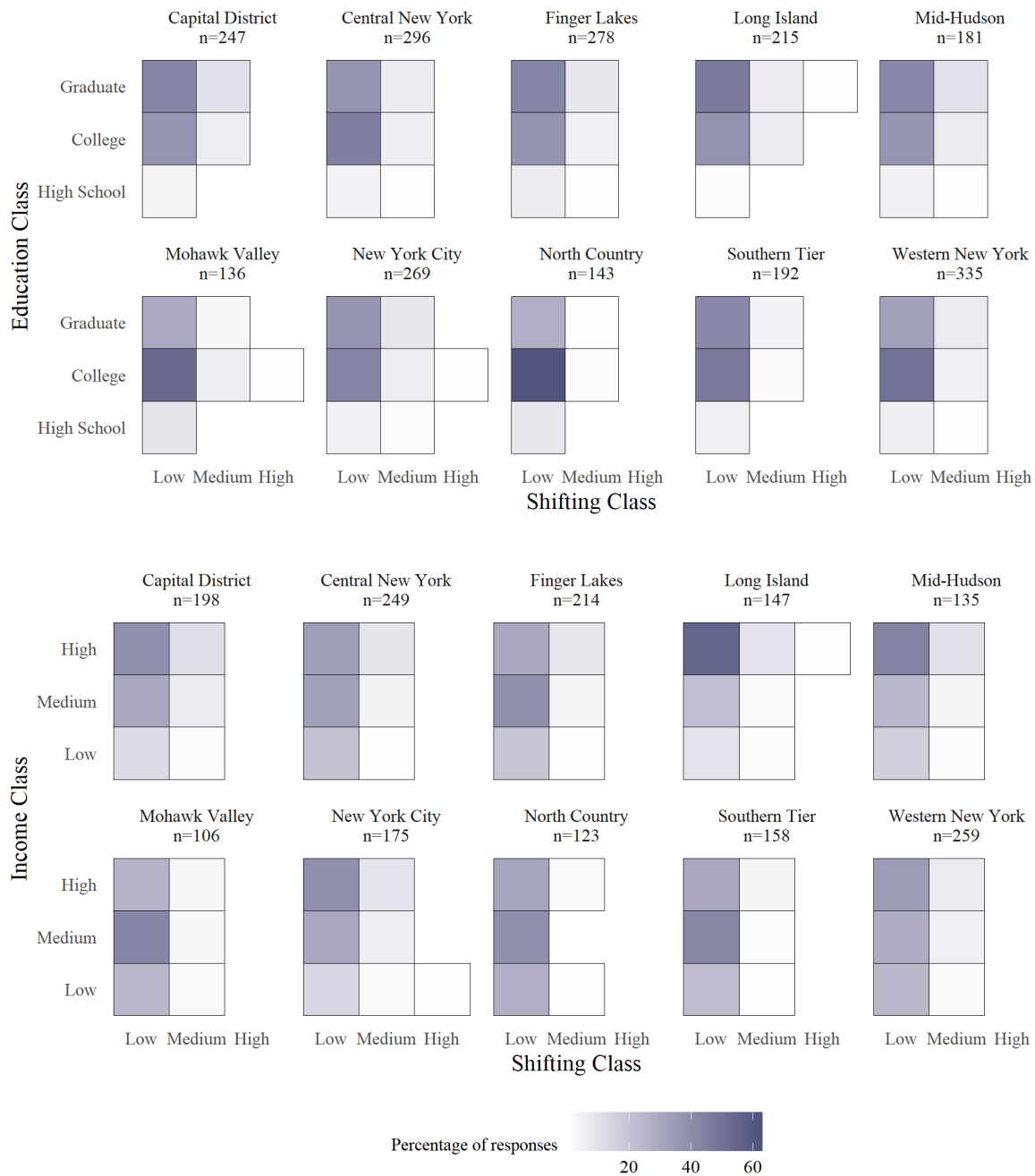


Figure 5. Shifting categorization and socioeconomic attribute heatmaps. Missing tiles indicate no responses were available.

Discussion

Overall, there was limited variation in technology adoption across EDRs; for each of the evaluated technologies, most EDRs saw comparable levels of adoption. This may be, in part, due to the technologies that were considered. Most homes have lights, TVs, and refrigerators, and as such, significant efforts have been made to make these technologies more efficient and

accessible through mandated standards and voluntary programs like ENERGY STAR. For example, more than 80% of TVs currently circulating on the market have an ENERGY STAR rating (Urban and Roth 2017). The pervasiveness of that efficiency in the market appears to have made its way into homes. Federal and state standards for appliances, such as those in New York Assembly Bill A10439, also contribute to this changing landscape over time as they establish requirements for efficiency. Standards have a long history of decreasing consumption for consumers across demographics and hold strong potential to continue doing so in the future (Mauer and deLaski 2020). Lesser adopted technologies like smart and remote-controlled ones are not quite as ubiquitous and have not yet seen comparable campaigns, likely contributing to the overall lower levels of adoption. Smaller-scale initiatives may be influencing the minimal variation that is seen in those categories.

While some trends could be identified across DSM capabilities and socioeconomic attributes, there was insufficient evidence to show statistical significance between the variables within the EDRs. Even still, the results for energy efficiency generally skew towards those seen in other studies where low-income residents and those with lower levels of education adopt fewer energy efficient technologies (Drehobl, Ross, and Ayala 2020; Mills and Schleich 2012). Through energy efficiency, homes decrease the overall demand on the electric grid and subsequently have the potential to provide energy, capacity, and non-wires solutions (i.e., deferring or removing the need for traditional transmission and distribution system upgrades) as grid services (Nubbe and Yamada 2019). For building occupants, the benefits of energy efficiency can be both monetary and non-monetary, accruing to the building occupant directly or to building occupants located nearby generation sources. Decreasing demand through energy efficiency can help lessen household energy burdens and costs associated with energy payments. This decrease in demand can also be particularly beneficial to vulnerable populations more broadly; when energy efficiency increases, demand for fossil fuel generation can decrease. This leads to improvements in air quality as well as in many respiratory, circulatory, and nervous system conditions in areas surrounding power plants (Westfall n.d.; ACEEE and PSR n.d.). Occupants in energy efficient buildings have also shown to suffer less from fatigue, headaches, and skin irritation (IEA n.d.).

Although shedding and shifting technologies have not been adopted to the same degree as energy efficient technologies, the benefits they are likely to provide building occupants is similar—a reduction in energy burden and improvement in health and wellbeing. This is especially true if the aggregate adoption of these technologies at scale is successful in decreasing peak demand and reliance on peaker plants, which tend to be high-emitting plants and often located in low-income neighborhoods (Krieger, McPhail, and Blythe 2020). Load shedding has the potential to provide the same grid services as energy efficiency but may also contribute contingency reserves, and load shifting can help avoid renewable curtailment and provide capacity and non-wires solutions (Nubbe and Yamada 2019). Beyond that, technologies capable of shedding and shifting like smart thermostats and smart lights can, for example, improve occupant comfort by intelligently adjusting temperature and lighting settings based on preferences. Trends across income and education levels for shedding and shifting capabilities in New York appear similar to that of energy efficiency. However, they are currently associated with lower ratings for shedding and shifting when compared to energy efficiency. As the building stock continues to evolve, it is important to consider how to fairly disseminate the benefits of GEB technologies to building occupants, including those who ultimately install the technologies and those who are unable or unwilling. Options for doing so are likely to come in

the form of policy actions and incentive programs and by better identifying and quantifying local value streams that are generated by at-scale deployment. The tenets of energy justice can be used as a framework for doing so.

Emerging from the environmental justice movement, energy justice is rooted in three tenets of justice: distributional justice, recognitional justice, and procedural justice (Jenkins et al. 2016; Jenkins 2018). Distributional justice focuses on the fair distribution of benefits and costs generated by energy technologies, consumption, and policies. To ensure a future GEB landscape promotes distributional justice will require both equitable access to GEB technologies as well as guaranteeing that changes within the energy system that result from GEB adoption at scale are realized fairly. This could mean developing programs to enable technology adoption in communities that have been historically excluded from such upgrades. Those programs could build upon existing efforts that embed energy efficiency within larger initiatives like providing affordable housing (Samarripas and Jarrah 2021). This might require targeted community engagement to reach low-income renters and directly incentivizing landlords to adopt GEB technologies. The existing landscape of load shedding and shifting technologies in New York generally skews towards populations with higher education and income levels. In this setting, incentives and educational programs that target populations with lower income and education levels could promote fair access to technologies as they become more cost efficient. Such programs might expand upon existing ones such as New York's EmPower program that offers no-cost energy efficiency solutions to income-eligible New Yorkers and the Solar for All program that offers subscriptions to community solar projects to income-eligible homeowners (NYSERDA n.d.).

In comparison, procedural justice, seeks to guarantee that all stakeholders have access to energy decision making processes. This could include new forms of community engagement in the process for creating electricity rates that enable GEB value streams, designing technology adoption incentives, and implementing GEB demonstration projects. If electricity rates are adopted to promote shedding and shifting, for example, this would require that households with lower income or education levels are engaged in that rate making process and are not disadvantaged from such actions.

Finally, recognitional justice requires that the unique voices in the energy system and their experiences are acknowledged and considered. To do this in the future GEB landscape could mean designing technology adoption programs to respond to multiple needs in high-priority communities. Again, GEB-technology incentives could be coupled with other needs identified by community member such as affordable housing. With few homes reporting high efficiency, shedding, or shifting capabilities also reporting a low income in New York, this might materialize through local governments working directly with community representatives and affordable housing developers to adopt GEB technologies in residential buildings while preserving their affordability.

Some scholars have begun to consider a fourth tenet within the energy justice realm: restorative justice (Hazrati and Heffron 2021). Restorative justice within the energy justice realm works deliberately to rectify past harms generated by energy decision making. This is particularly salient for residential homes, which have long been influenced by unjust and racist policies, like redlining, leading to limited economic and educational opportunities (Lewis, Hernández, and Geronimus 2020) and many fossil fuel plants being located in low-income neighborhoods (Krieger, McPhail, and Blythe 2020). Ensuring that occupants are comfortable in their homes and reap the benefits of GEB technologies as a way to rectify these past injustices

should be considered in the transition to a clean and just energy future. If GEB technology adoption at scale enables fossil fuel plants to be decommissioned, restorative justice would prioritize decommissioning in communities that have been disproportionately burdened in the past and actively support technology adoption in those communities. These pillars of justice can ultimately serve as a framework for developing GEB policies and be used as tools to understand how the many benefits of GEB technology adoption can be disseminated among different populations.

Limitations and Future Work

While this work has shown that energy efficient technologies are more prevalent than shedding and shifting technologies in New York's residential building stock, the results were limited by the information collected by the survey. This analysis was successful in evaluating some technology adoption at an EDR level, but insufficient information at a county level made more granular analysis unfeasible. Furthermore, some of the technologies of interest in the dataset, such as home energy management systems, did not have adequate reporting to meet the conditions for inference at the EDR level. As such, there was an imbalance in the number of technologies considered for energy efficiency compared to shedding and shifting. This could, however, reflect the current state of understanding of those technologies if people preferred not to answer, did not know, or did not submit a response for that portion of the survey. The DSM strategies considered were also limited to energy efficiency, shedding, and shifting. No technologies had sufficient data to evaluate modulation in the dataset, and the dataset did not have information on generation sources. Future work should consider these additional DSM strategies given the potential for GEB technologies to engage in those behaviors and include other home modifications achieved through weatherization as well.

The survey data was also limited in its socioeconomic characteristics, only asking respondents to report income and education level. Some demographic information was available including the age ranges of household members, but future work should align the building stock assessment with additional data sources to expand upon the intersection of socioeconomic status and demographics, evaluating the data for statistical significance between different population attributes. This work can include an exploration of renters versus homeowners. It is highly recommended that this is done at a more granular level than the EDR given the higher probability of identifying differences between geographic regions. Using relative income levels to identify low- to moderate-income homes is also recommended.

Finally, the extent to which the adopted technologies can participate in each DSM strategy is not included in the analysis. Smart lights, for example, may only be able to shed a small portion of a home's demand at a given time compared to the energy shed by a smart thermostat in the same situation, provided the building occupant is flexible in their temperature preferences. Ultimately, some technologies will be able to provide more capability than others, which should be considered in future work.

Conclusions

This analysis evaluated the existing distribution of GEB technologies in the residential building stock in the State of New York by EDR. Technologies were mapped to the DSM strategies they enable and cross-examined with socioeconomic attributes. Energy efficient technologies are reported in more homes across EDRs compared to technologies capable of

shedding or shifting load, and limited trends were identified across socioeconomic attributes and DSM capabilities in the dataset. However, to ensure that the future GEB landscape contributes to both a clean and just energy system, it is critical to track technology adoption now to inform policies and incentives that enable such an outcome. Four tenets of energy justice – distributional, recognition, procedural, and restorative – were presented as a framework for doing so. GEBs hold the potential to provide benefits to the electric grid as well as building occupants, but holistic and systemic thinking will be necessary to ensure those benefits are fairly distributed.

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