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Clean Energy Utility for Multifamily Housing in a Deregulated Energy Market

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Abstract

Energy efficiency and renewable energy (EERE) investment in multifamily residences in the United States has not kept pace with investment in resident-owned facilities. Split incentives, where owners cannot benefit economically from energy cost savings for residences and resident investment in EERE is not feasible, have posed a significant barrier. A clean energy utility is posited to circumvent this barrier. This utility would be responsible for power purchase from the grid, ideally as a real-time purchase agent from the grid manager; investment in energy efficiency and renewable energy; and demand management through control of water heating, as well as supply-side management through deployment of stored solar at near-peak grid power purchase cost. A clean energy fee is posed for recovery of costs, in contrast to typical consumption strategies (per kWh).

A case study approach is employed to evaluate the feasibility of this type of utility of reducing carbon production in this building sector. Considered in the analysis is a 2008 multifamily facility located in the Midwest of the U.S., with apartment level interval meters for both power and water. Historical data from these meters were used to assess the savings and demand-side management potential from investments in improved efficiency lighting, refrigeration, heat pumps, and water heaters, as well as investments in solar PV and storage for supply-side management. The results show that the packaged retrofit EERE investment could yield costs for residents and profits for energy manager comparable to those in the current residential pricing scheme, while reducing grid-sourced energy by 42%. When solar PV and battery storage are added to the solution, it is shown that a clean energy fee structure can cost-effectively drive savings to over 54%. For new construction, even deeper cost effective savings are realizable. This research demonstrates the potential to drive deep energy savings in the multifamily building sector that can lower costs to residents through the establishment of clean energy utilities which recover investments in energy efficiency, demand management, and solar PV/battery systems through resident clean energy fees rather than consumption fees.

1. Introduction

Customer-funded energy efficiency programs more than doubled over the latter half of the past decade, increasing from roughly US$2 billion in 2006 to US$4.8 billion in 2010 [1] . A recent study estimates that by 2025 this spending will rise to between US $6.5-16.5 billion. However, even with recent investments, energy consumption in the building sector has remained approximately flat [2]. Therefore, it is easy to argue that 'business as usual' through reliance on customer-funded energy reduction will not help the US achieve the substantial energy and carbon emissions reduction needed to respond to the looming climate change challenges.

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One-third of the U.S. population lives in the country's 500,000 multifamily buildings [3], but reducing energy use in this sector is especially problematic. An energy efficiency gap for this sector relative to owner-occupied residences and rented single-family residences has been observed. This gap widens with lower residential income. A recent study documented that rental multifamily residences had energy intensities that were 37% higher than for owner-occupied multifamily units (i.e. condos or co-ops), 41% higher than for renter-occupied single family detached units, and 76% higher than in owner—occupied single family detached units [4]. This gap is partly correlated to 20% higher inhabitant densities, the significantly less energy efficient rental buildings [5], and to the fact that energy costs are most typically bundled into rental payments. There is some evidence that the inability of renters to see their energy bill directly leads also to less conservation behavior. The likelihood of turning down the heat at night is 13% higher among the households that pay for gas [6]. Furthermore renters in the U.S. and Canada who do not pay their own utilities tend to keep their apartments warmer while they are out than those who pay for their own heat [7] [8]. Further, a 2014 study of 3,000 apartments showed that tenants used 30% more heating energy when owners paid the bill [9].

A number of obstacles to energy efficiency and adoption of renewable energy exist for this sector. Foremost is the 'split incentives' barrier which emerges because the costs of energy efficiency improvements are paid by the building's owner while the economic benefits of the resulting savings largely benefit the tenants if they pay the energy costs. Other impediments include: the diversity of multifamily building stock; the dispersion of building ownership – with many multifamily residences having absentee owners; the lack of access to financing for building owners; the lack of data about multifamily energy use and retrofit performance; and some legal and regulatory barriers [1]. Furthermore, like most buildings in the residential sector, even if an economic case could be made for investment, an underlying impediment to action is an inability to systemically reach the population of multifamily building owners to educate them about the opportunities present to them.

To encourage owners to make investments in energy efficiency, the availability of attractive utility, tax, and government incentives are likely important , as well as an emerging tenant-driven demand for green options [10]. Collectively, however, these drivers have not yet realized sector-wide action.

One pathway to achieve systemic energy reduction is offered through the model provided by Virtú Investments, a large multifamily-facility manager. This organization, which embeds energy costs in rental fees, has used PACE financing for EE investment to realize energy savings of 12%. Their economic model has been designed to be operationally cost neutral for owners with no cost penalty for residents, with rental fees unchanged after investment. Energy cost savings are simply used to pay back the property assessment [11]. While operationally cost-neutral for owners they benefit through the increased property value realized from the investments. They also potentially benefit from being able to advertise their facility as a green facility to potential renters. Thus, occupancy rates could increase.

Another alternative emerges from a partnership between building owners and energy efficiency service companies and utilities through energy performance contracting [12]. In this model, energy performance contractors provide the investment in energy efficiency, and recover their investment via a contracted cost recovery with the building owner [13]. Another option for cost recovery of energy efficiency investment, is through utility managed investment, with subsequent on-bill repayment (OBR). According to the ACEEE, currently utilities in at least 23 states have implemented or are about to implement OBR programs [14]. Both of these options have wide-scale viability, however, performance contracting service commitments will necessarily be conservative in order to insure cost recovery. Second, OBR still needs a broker between the utility and building to identify the best investments.

A key for deep penetration of these options is the establishment of a utility business model based upon the decoupling of utility revenues from sales [15], [16] , where residential energy fees aren't linked directly to energy consumption. One recent manifestation of this decoupling has emerged in Delaware in the form of a "Sustainable Energy Utility." The benefit of this type of utility is that "energy users can build a relationship with a single organization whose direct interest is to help residents and businesses *use less energy* and *generate their own energy cleanly"* [17]. While the structure proposed in Delaware was not based upon establishing an economically advantageous model, it at least informs the value of utility led clean energy in reaching customers.

One means to establish an economically advantageous utility-building partnership in the multifamily building sector is in the growing third-party utility sub-meterering industry. In 2011, a GreenBiz article stated "It's starting to look like the next frontier is energy submetering -- using IP-connected sensors and meters to fine-tune your energy management data" [18]. This industry is already 'on-the-ground' establishing relationships with building owners throughout the U.S. It could easily adapt to become the "Sustainable Energy Utility" for multifamily buildings.

This paper presents a model of a clean energy utility for apartments that leverages the best elements of existing models, including the use of PACE financing for investment in EERE investment, energy performance contracting coupled to some type of OBR, and submetering of individual apartment units and common spaces. Uniquely, however, the model presented here utilizes apartment-level real-time energy (and water) information to evaluate the best alternatives for EERE investment, as well as demand dependent energy pricing. However it has been shown that energy dependent pricing is not enough for energy efficiency improvement in residential sector. On average it shifts about 2.44% of the peak usage to off peak [19]. To fully take the advantage of real time or energy dependent pricing the potential for demand-side and supply-side management has been considered. The benefits of demand side management in addition to energy efficiency improvement and energy bill cost has been discussed in [20]. Further, a clean energy fee structure is proposed, whereby residents pay a fixed energy fee that is not directly linked to their consumption in order to recover costs from EERE investment yielding deep carbon reduction. Disconnecting the resident energy fee from consumption is shown to be essential in order to drive economically advantageous deep carbon reduction.

2. Methodology

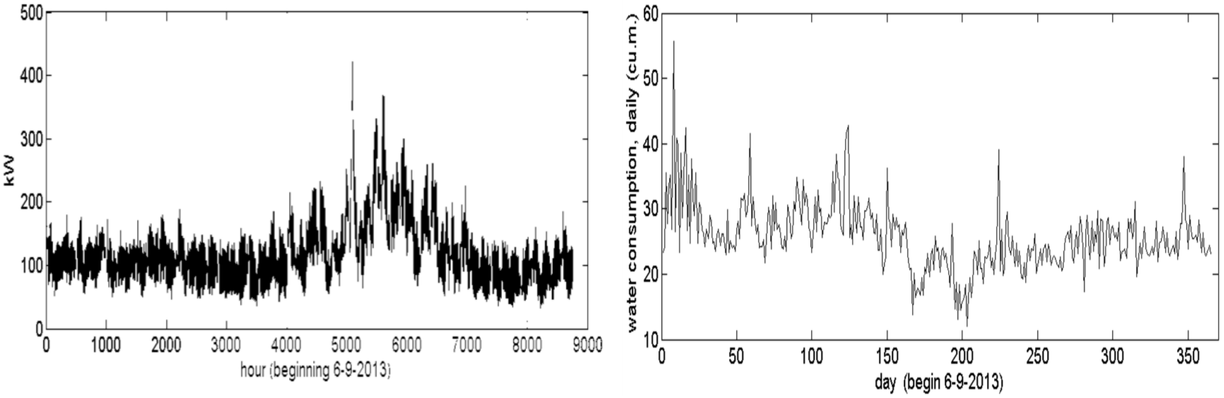
Five principles guide the model of a multifamily building clean energy utility. First, this clean energy utility is responsible for billing residents for the energy services offered. Second, it is responsible for collection and analysis of energy, and possibly, water data to continuously improve the proposed energy fee structure. Third, the utility is responsible for prioritizing clean energy, demand-side and supply-side management investments. Fourth, it is responsible for guiding the multifamily residence owners through clean energy financing and the process to access federal, state, and local tax credits, as well as utility rebate incentives, for energy efficiency and renewable energy investment. Finally, the clean energy utility is responsible for potential sales of capacity, frequency regulation and demand response and energy efficiency relative to a Regional Transmission Organization (RTO). Conceivably, if this utility serviced a sufficient number of multifamily residences, they could be a certified energy retailer for the RTO, purchasing power in the day-ahead Reliability Pricing Market (RPM).

A multifamily residence in Columbus, Ohio, U.S. serviced by a third party sub-metering agency is used here as a case study. This facility has 220 apartment units, which are variable in size. There are effectively three apartment types: small one-bedroom; mid-sized two-bedroom apartments; and large three-bedroom units. This apartment complex was built in 2008, and, as with many or most multifamily residences, to minimum code standards, with minimum efficiency lighting, appliances, and HVAC systems. The facility is all electric, with heating provided by unit-level air-source heat pumps. Each apartment has an emergency heating switch, which is both automatically and resident controllable, to toggle the heating to an electric resistance heating mode as needed. It has been found that this switch often remains on during the whole of the winter.

2.1 Baseline Energy/Power

To estimate energy savings and demand impact from EERE investments, it is essential to establish a baseline for energy and power consumption for the residences for the current energy systems. This baseline should include estimation of the hourly and annual aggregate (for all apartments) energy use for heating, cooling, water heating, and all of the major appliances. Analysis of these data enables prediction of energy savings and impact on hourly consumption as a result of energy efficiency upgrades and demand/supply-side management.

Data to establish the baseline condition are available because the company managing the facility invested in apartment-level sub-metering for energy and water consumption. This includes average hourly power for each apartment and common space and twice-daily, unit level water consumption. Figures 1a and 1b show respectively the aggregate (sum of all apartments) hourly power and twice daily aggregate water consumption for the period of time from June 9, 2013 to June 8, 2014.



(a) (b)

Figure 1. a) Average aggregate hourly power and b) Daily aggregate water consumption (m^3)

The aggregate energy consumption for this baseline condition can be disaggregated into weather-dependent and weather-independent contributions using a five parameter regression of monthly aggregate energy consumption with monthly average outdoor temperature. Figure 2 shows the actual data and the regression fit. The fit parameters are noted in the figure. The r-squared value for the fit is 0.97. From this regression, the weather normalized annual heating, cooling, and weather-independent energy (including hot water) can be calculated using the Prism methodology [21] [22], as shown in Eq. 1. Table 1 shows the resulting annual energy estimates for each energy term in comparison to estimates from the Energy Information Agency’s Commercial Building Energy Consumption Survey (CBECS).

$$E_{heat,annual} = \sum_{month=1}^{12} HS \times \left(T_{bal,h} - T_{month}\right),$$
$$E_{cool,annual} = \sum_{month=1}^{812,760} CS \times \left(T_{month} - T_{bal,c}\right), \text{ and} \qquad (1)$$
$$E_{weather\ indep.} = \sum_{month=1}^{12} Baseline_{month}$$

In Eqns. 1, the annual heating and cooling energies (kWh) are given by $E_{heat,\ annual}$ and $E_{cool,\ annual}$, respectively, and the annual weather-dependent energy use is $E_{weather\ indep.}$. The heating slope (HS) is given in units of kWh/°F, as is the cooling slope, with the baseline (weather-independent) energy consumption given by $Baseline_{month}$. T_{month} is the average monthly temperature and the balance-point temperatures for heating and cooling are given by $T_{bal,h}$ and $T_{bal,c}$, respectively.

Table 1. Annual weather normalized energy consumption for the aggregate apartments by energy type in comparison to U.S. Midwestern consumption for typical multi-family residential residences (shown in parentheses)

Annual Energy, kWh Actual (RECS [23]**)**		
Heating	**Cooling**	**Weather Independent**
207,900 (1,006,000)	67,785 (47,480)	647,000 (773,460)

The hourly heating and cooling power throughout the year is estimated using the regression results for cooling and heat slopes and balance temperatures according to Eq. 2. In Eq. 2 730 is the average monthly hours per month and P_{cool}, P_{heat} and $P_{weather\ independent}$ are the power demands (kilowatts) for cooling, heating and baseline for hourly temperatures, T_{hr}.

$$P_{cool} = CS \times \left(T_{hr} - T_{bal,c}\right)/\ 730,$$
$$P_{heat} = HS \times \left(T_{bal,h} - T_{hr}\right)/\ 730, \quad \text{and} \qquad (2)$$
$$P_{weather\ independent} = Baseline\ /\ 730$$

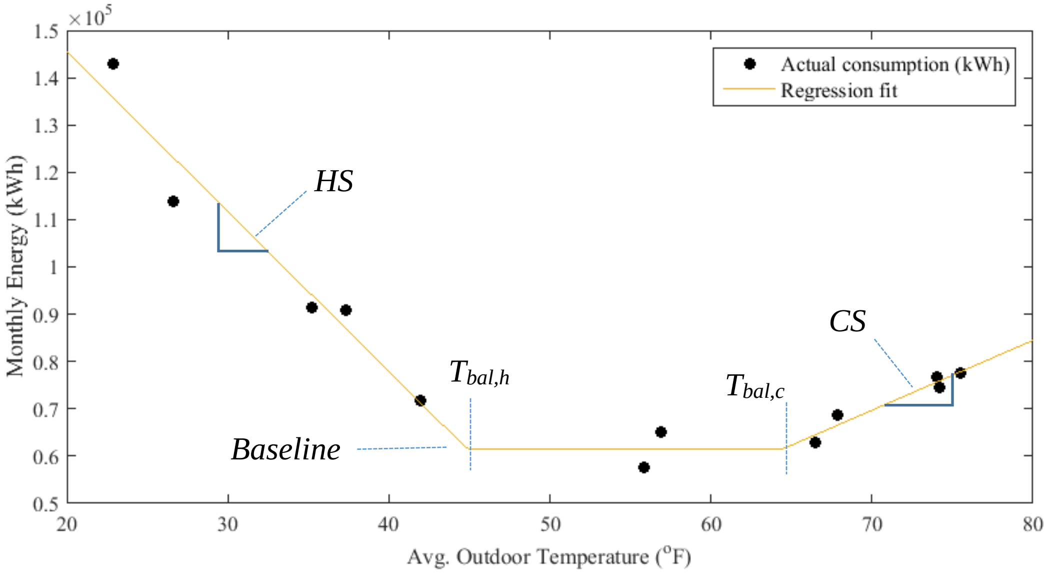


Figure 2. Aggregate monthly consumption (kWh) versus monthly average outdoor temperature (°F)

Figure 3 shows the estimated aggregate heating, cooling, and weather independent power. It is apparent from this figure that in the winter, weather-dependent heating energy is dominant, whereas for the rest of the year weather-independent energy consumption is dominant.

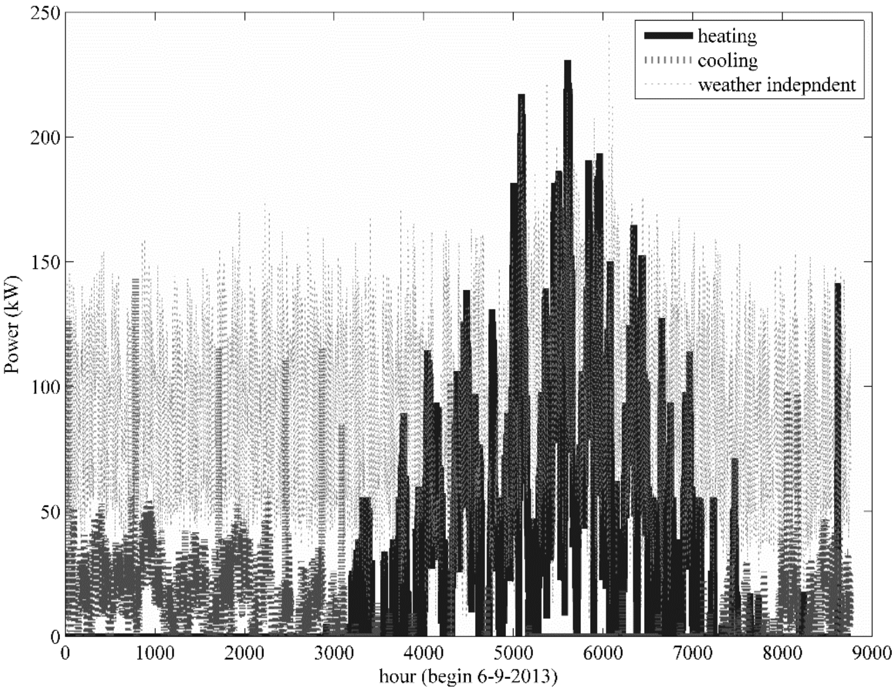


Figure 3. Hourly power for the aggregate set of apartments for heating, cooling, and weather independent use for the time period beginning 06-09-2013 0:00 to 06-08-2014 24:00

Next, because we'd like to estimate the impact of upgrades and possibly demand management of other high power consuming systems (water heating, lighting, and refrigeration) in apartments on the aggregate demand profile, it is necessary to develop typical demand profiles for these systems. For water heating, the daily hot water consumption is estimated from the measured unit level twice daily water consumption (which includes both hot and cold water) and the assumption that approximately 43% of the measured water consumption goes toward hot water and that the average hot water temperature is 54.4°C [24] [25]. The aggregate hourly water heating consumption is estimated from this daily consumption and the normalized typical hourly profiles for weekday and weekend days obtained from a large collection of New York state apartments [26], assumed to represent broadly similar behavioral patterns. Using these typical hourly profiles and the aggregate daily consumption, the hourly water heating energy consumption for each day can be estimated from the measured daily consumption according to Eq. (3).

$$E_{DHWday,hr} = \forall_{day} \times f_{HW} \times \rho_{H20} \times c_{p,H20} \times (T_{DHW} - T_{CW}) \times f_{hr} \qquad (3)$$

where $\forall_{day}$ is the measured daily volume of water used, f_{HW} is the fraction of water consumption used for hot water (assumed 0.43), ρ_{H20} and $c_{p,H20}$ are the density and specific heat of water, T_{DHW} is the water heater water temperature (54.4°C), T_{CW} is the cold water temperature (10°C), and f_{hr} is the fraction of daily water consumption used in a particular hour. This last term is different for weekdays and weekends.

Lighting and refrigerator demand profiles are based upon knowledge of the systems present in each apartment. All lighting is presently incandescent. The associated U.S. EIA annual average consumption in a multifamily residence for this type of lighting is 1,798 kWh [27]. The refrigerators present in the apartments have the minimum efficiency refrigerators required of refrigerators in 2008, with a nominal annual energy consumption of 566 kWh. Given these annual consumption estimates and typical normalized hourly and monthly variation for both given by the US Department of Energy – Energy Efficiency and Renewable Energy Building America Analysis Spreadsheets resource [28], hourly consumption for lighting and refrigeration can be estimated over the entire year.

2.2 Energy Efficiency and Renewable Energy Measure Characteristics

The clean energy utility will be responsible for all investments in EERE, demand management, and supply-side management. These investments will be made facility-wide. Thus, for example, if heat pumps are to be replaced, they will be replaced in all units. Ultimately, their task will be to recover the cost of their investments via residents' energy payments.

Table 2 summarizes the current system energy consumption, the proposed improvements, and the energy reduction percentage associated with each measure considered in this study. The measures considered include both energy efficiency improvements and solar PV/battery systems. The energy efficiency investments include changing 60W incandescent lights to LED equivalent lighting, refrigerator upgrades from minimum 2008 efficiency to current Energy Star efficiency, water heater upgrade from minimum electric water heater efficiency to heat pump water heater, and air source heat pump upgrades from a minimum 2008 efficiency system to a best 2015 system.

Table 2. Energy efficiency and renewable energy upgrade details for

Measure	**Qty**	**Description**		**% Energy Reduction (or efficiency)**
		Current	***Improved***	
Lighting[1]	26 lamps	Incandescent, 60 W bulbs	LED, 8.5 W bulbs	84
Refrigerator	0.42 (m^3)	Std. (2008)	Energy Star	37.6
Water Heating	0.23 (m^3)	Std. electric	Heat pump	66
Heating	7 (kW)	Std. heat pump	High eff heat pump	37.6
Solar PV	--		18% efficiency	
Battery			Vanadium Flow	95% (efficiency)

[1] Assumed is average light bulb power = 51.7 W, 1.7 hr/day on time

2.3 Clean Energy Incentives and Financing

The clean energy utility should necessarily take advantage of clean energy financing and purchase incentives (utility rebates and tax credits). There are increasing opportunities for clean energy financing. However, the financing mechanism associated with Property Assessed Clean Energy (PACE) is considered here, as it is representative of best practices in the industry. This financing mechanism can take advantage of loan durations of 15 years or more with loan rates as low as 4.5%. Presently, the state of Ohio offers no tax incentives. However, many other states do. Thus, the results presented for this Ohio case study will under-predict the value of a clean energy utility in other states.

Finally, local utility district rebates are considered for each measure included in the study, which are quite variable across the U.S. Table 3 summarizes the assumed capital costs and rebate incentives relied upon for this study. It should be noted that the capital plus installation cost associated with solar PV references the cost of access to Community Solar projects, which offer an economy of scale not available to single buildings [29]. The cost of battery technology in 2015 is now already below predictions made in 2007 for 2020 [30], with the most recent cost for such batteries reporting to have decreased to below $300/kWh [31]. ARPA-E has established a goal of $100/kWh for this technology [32]. Finally, flow battery costs of $200/kWh used in this study are based on projections for 2017 to 2018 [33] . Federal tax credits for solar energy apply to batteries linked with solar PV.

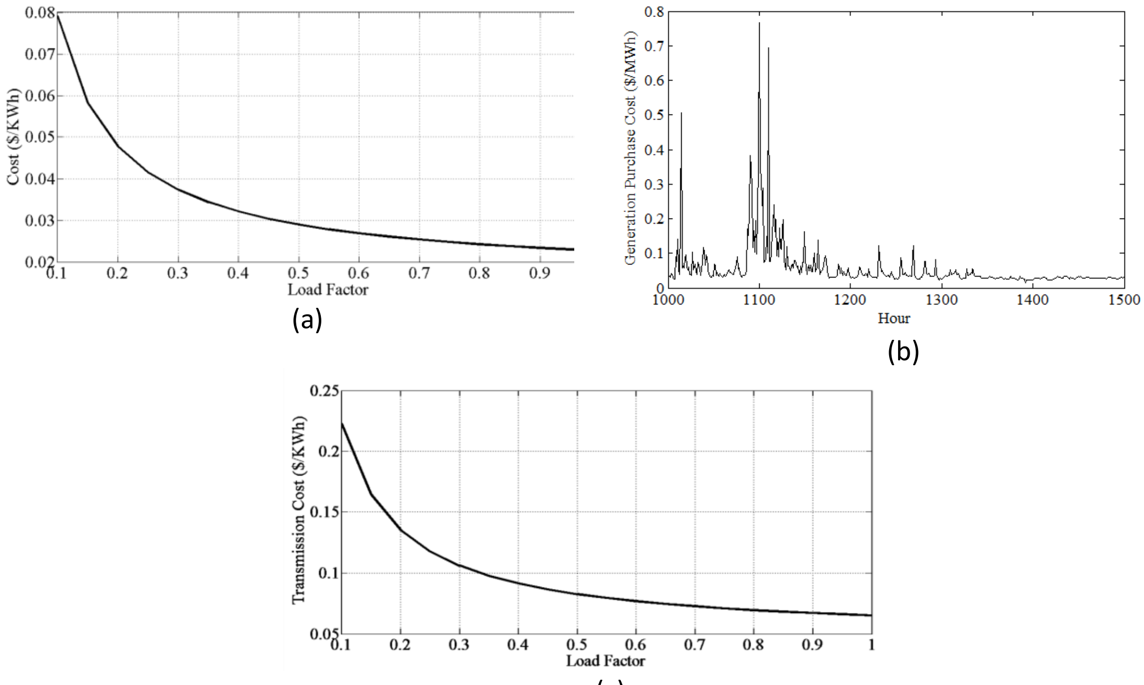
Table 3. Clean energy upgrades capital plus installation costs and rebates/tax credits

Measure	**Costs Per Unit, Retrofit ($/unit)**	**Rebate/Tax Credit Per Unit ($/unit)**
Lighting	$0.1/W	$0.4/W reduced
Refrigerator	$650/unit	$50/unit
Heat Pump Water Heater	$1,000/unit	$300/unit
Heat Pump	$3,000/unit	$500/unit
Solar PV	$1.55/W	30% tax credit
Flow Batteries	$200 kWh	30% tax credit[1]

[1] Federal solar tax credit applies to batteries if used with solar PV.

2.4 Grid Power Purchase and Energy Sales Pricing

It is clearly not possible to consider in this study all of the large number of existing electricity pricing schedules. Thus, representative cost scenarios available in Ohio are considered. Two particular strategies are used in this study. First, is a pricing schedule (Pricing Scenario 1) available from a local energy retailer having the greatest demand risk to the customer, as this type of pricing scheme offers the best opportunity for grid purchase cost savings for the clean utility optimally managing demand and supply. This pricing schedule offers a per kWh charge for each month that depends upon the monthly load factor [mean(power) / maximum(power)] and total power consumption [34]. This power pricing schedule is what the sub-metering company servicing the apartment complex presently uses. Second is a grid purchase pricing strategy (Pricing Scenario 2) associated with day-ahead power purchase in the Reliability Pricing Market (RPM) organized by the Regional Transmission Organization (PJM is the relevant RTO for the considered city). For this scenario, the utility would be responsible for effectively purchasing power real-time from the grid. This pricing scenario is considered because it offers even greater opportunity for grid power-purchase cost benefits from optimal demand- and supply-side management. A lower load factor is associated with higher energy cost across a utility district or grid because it forces use of less efficient and more costly power generation assets. Figure 4a shows the monthly grid pricing generation fee versus load factor for Pricing Scenario 1 in the monthly kWh demand associated with the apartment complex. Figure 4b shows a representative hourly cost schedule for power generation for Pricing Scenario 2. The transmission cost schedule for both schedules is identical and is as given by Figure 4c [34].



(a)

(b)

(c)

Figure 4. Representative generation purchase cost structures through a (a) demand beneficial commercial utility tariff and (b) through real time pricing on the RTO in July 2014; (c) transmission cost schedule

The residential pricing scheme would be variable, with the maximum cost associated with the tariff-rate charged to residents, which in Ohio would be about $0.165/kWh. This study seeks to determine a clean energy fee for each resident to recover investment in EERE, and which is bounded on the high end by the residential tariff price.

2.5 Clean Energy Fee Methodology

In this section, a per-resident monthly clean energy fee methodology for the clean energy utility is developed to recover investments in the EERE measures shown in Section 2.2. A uniform fee structure for each residence is envisioned. In general the fee proposed begins with the idea that if an investment were to be made in one technology, it would be made for each residence. Thus, for example, if lighting were upgraded, then the lighting in each unit would be improved. A loan would be used to finance all investments in this technology. The resulting annual loan payback assigned to each residence would be determined by simply dividing the overall loan payment by the number of residences. This per resident loan payment needs to be included as part of the clean energy fee. Additionally, the per resident clean energy fee for a specific energy system (*e.g.*, lighting, water heater, etc…) has to account for the power purchase cost from the grid needed to power the specific system for each residence. Thus for example if the clean energy utility paid $X for all lighting energy from the grid for the complex, this cost would be distributed equally to all residents. The clean energy fee would include this cost to the utility. Note that in this study, the clean energy fee doesn’t not consider energy pricing escalation.

The following provides more details about the clean energy fee for: energy efficiency investments; as affected by demand-side management; and as affected by investment in solar PV and battery storage with supply-side management.

Energy Efficiency Investments

A clean energy fee structure per resident is proposed to recover the total energy efficiency investment and grid purchase cost for each upgrade, within a range bounded as follows. The minimum clean energy fee associated with a specific upgrade is associated with the per-resident loan payback for that upgrade and the per-resident grid purchase cost for power purchase from the grid after upgrade, as shown in Eq. 5.

clean energy fee, monthly, minimum,*j* =

$$\left(\sum_{i=1}^{N_{years}} loan\ payment, annual, i, j + \overline{grid\ purchase,}\, j\right)/N_{residences} \tag{4}$$

where $loan\ payment, annual, i, j$ is the total loan payment for efficiency measure, *j*, for all residences, $\overline{grid\ purchase,}\, j$ is the total power purchase cost for a year for the complex for measure, *j*.

The maximum monthly clean energy fee for each *j*th measure should be associated with the current mean of annual energy sales for each residence, as the investment in clean energy for each apartment should realize a fee that should not increase costs to residents. Thus,

$$\text{clean energy fee, monthly, maximum,}j = \overline{grid\ sales, current}\ , j\ /\ N_{residences} \tag{5}$$

Key to this methodology is the need to determine the average monthly grid purchase cost ascribed to each energy system, $\overline{grid\ purchase,}\, j, 1$ via two power purchase schedules. This requires evaluation of the impact of the energy efficiency investment on the demand. The first step in the process is to determine the baseline or current annual costs for each energy system independently. This determination relies upon the aggregate annual and hourly power estimates for each measure as described in Section 2.1. The flow chart shown in Figure 5 describes the process for establishing these baseline energy costs for each measure; in this case, for lighting power. The current aggregate hourly power obtained is used to estimate a grid purchase unit cost (cost/kWh) for both power purchase pricing schedules. This cost is then applied to the estimated power or consumption for the measure. For Pricing Scenario 1 which establishes a monthly per kWh cost based upon the monthly load factor for the aggregate power, c_n,, the per measure cost for the month is determined knowing the total consumption for the month, X, and the fraction of this energy purchased for measure j, f_i. The monthly grid purchase cost for this measure is thus: $f_j c_n, X$. For Pricing Scenario 2, the hourly grid purchase cost per kWh is determined from the RTO. The product of this hourly unit cost with the estimated hourly consumption for the measure determines the measure cost for each hour. Finally, energy sales associated with the energy use for each measure are calculated by multiplying the monthly kWh charge for energy sales to residents by the monthly consumption for each measure.

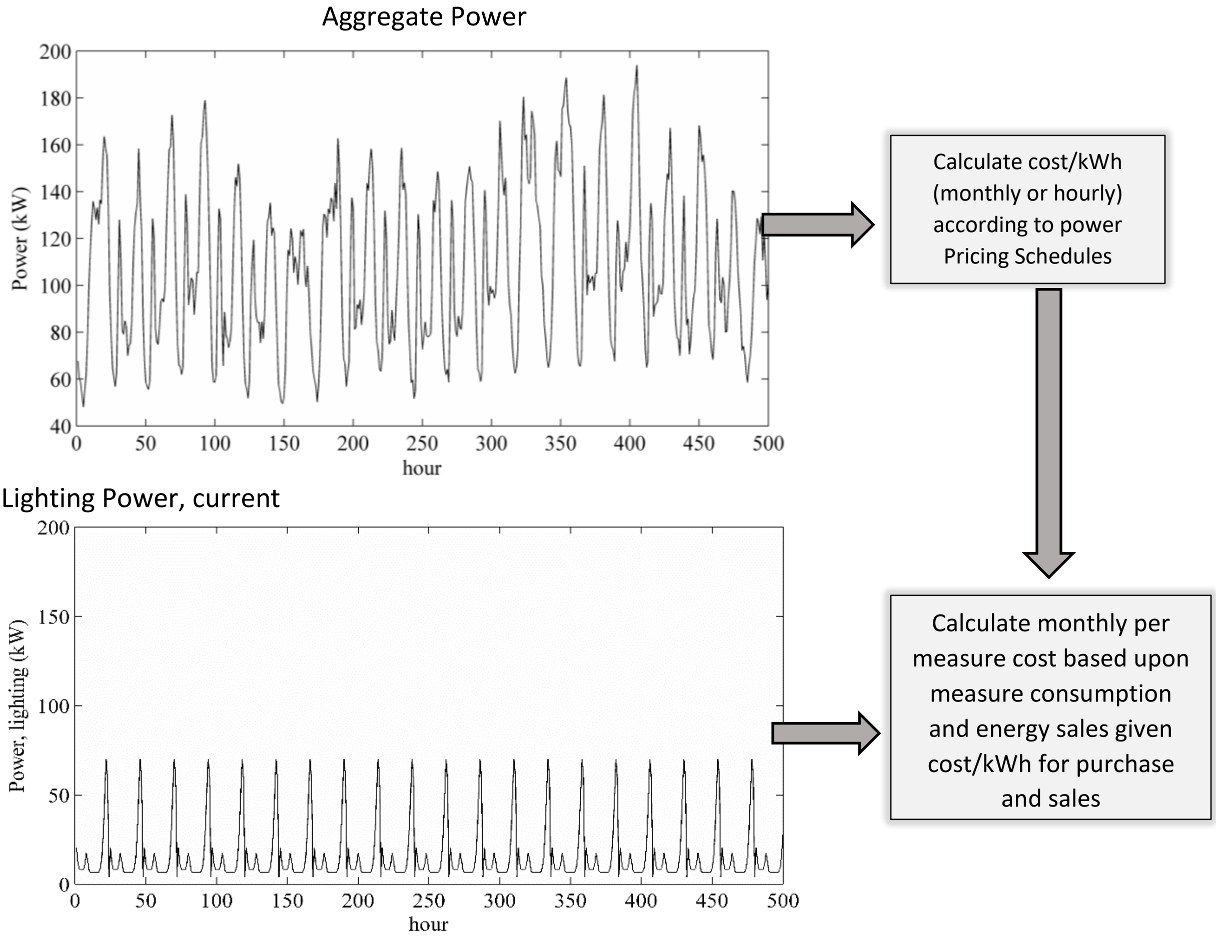
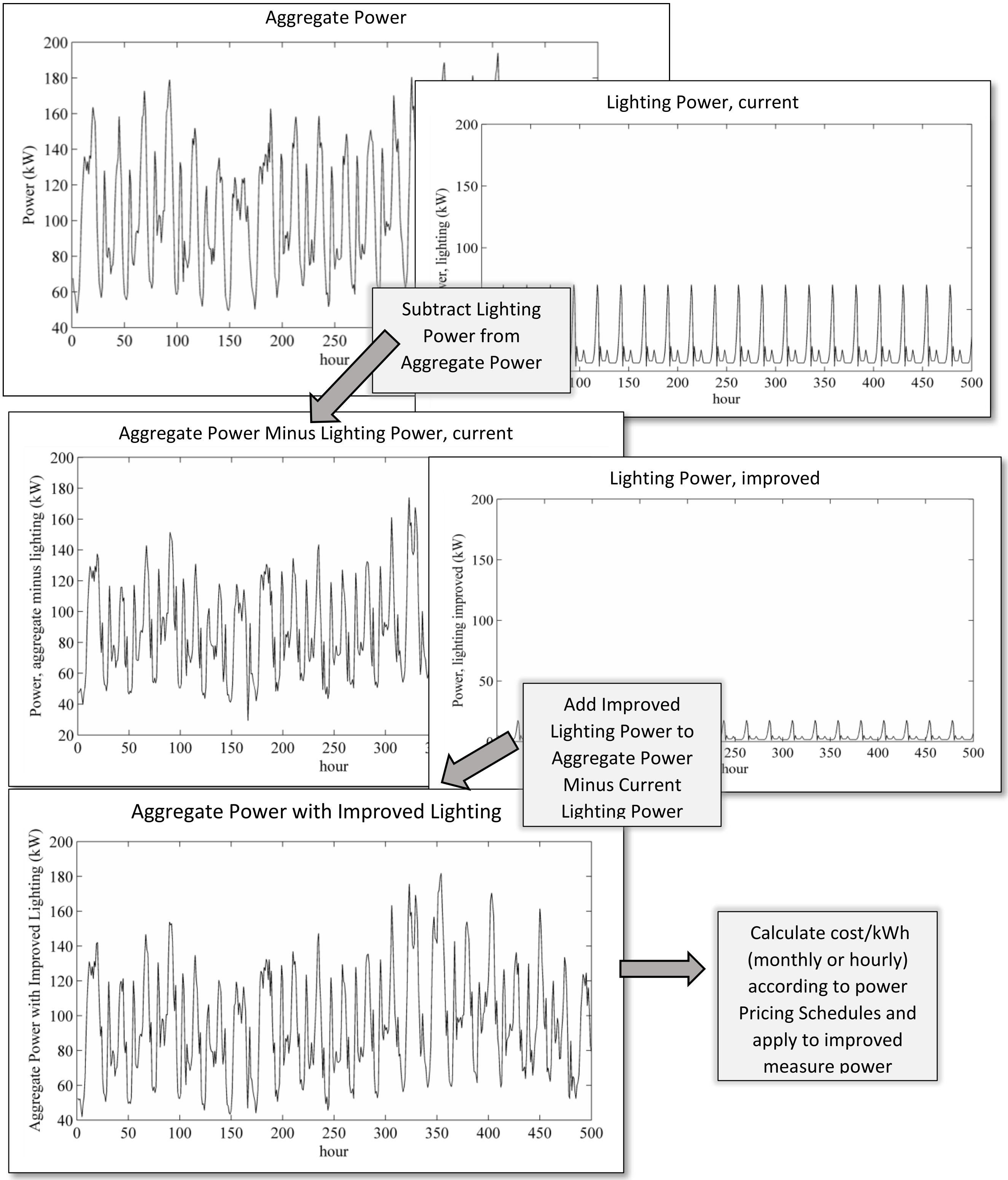


Figure 5. Methodology for calculating per measure power, current

Figure 6 details how the per-measure grid purchase and sales costs were calculated for both Pricing Scenario post-retrofit. Step 1 is to subtract the current measure power (lighting shown) from the current aggregate power. This yields the aggregate power minus lighting power. Next, the improved lighting power is added to this difference. This yields an estimate for the aggregate power post-retrofit. This aggregate power is then used to estimate the unit energy cost for grid purchase of lighting for both power pricing scenarios. The unit costs can then be applied as above to the improved measure consumption to estimate the power purchase cost each month attributable to the improved measure. Certainly, this cost is less that associated with the current measure condition. Additionally, the energy sales for the improved measure can be calculated based upon the sales unit cost and the improved measure consumption.


Aggregate Power

Lighting Power, current

Subtract Lighting Power from Aggregate Power

Aggregate Power Minus Lighting Power, current

Lighting Power, improved

Add Improved Lighting Power to Aggregate Power Minus Current Lighting Power

Aggregate Power with Improved Lighting

Calculate cost/kWh (monthly or hourly) according to power Pricing Schedules and apply to improved measure power

Figure 6. Improved per measure costing schema for the energy efficiency measures

With monthly per resident clean energy fees established for each energy efficiency measure, a packaged clean energy fee can be established for a collective group of measures, as given by Eq. 7.

$$\text{clean energy fee, monthly, total} = \sum_{j=1}^{N_{measures}} \text{clean energy fee, monthly, j} \tag{6}$$

Finally, it is envisioned that the clean energy utility can also derive cost benefit from demand and supply-side management. This cost benefit can be melded into clean energy fee developed for residents as described below.

Demand-Side Management

The demand-side management effect on the clean energy fee is associated with reducing grid power costs by deferring demand to reduce grid purchase cost the most. There are three clear opportunities for multifamily demand management: heating, cooling, and water heating. The only demand side management considered here is water heater demand management using smart water heaters, which enable a utility to turn-on or turn-off intelligently without sacrificing in any way the comfort of the residents. Given that recovery time for most water heaters, e.g. the time required to heat the water to the set-point hot water tank temperature, is less than or just over one hour, then the peak water consumption occurs with generally only a 60 minute time lag to water consumption. Thus, water heater demand control can readily be adjusted with occupancy. Elamri demonstrated previously that water heater management in residences had significant benefit on demand in a residential smart grid [35].

The water-heater demand management approach for Pricing Scenario 1 is based upon the following assumptions. First, it is assumed that the total water heating energy consumption for each day is fixed and equal to the historical estimated hourly hot water consumption. Thus,

$$\sum_{hr=1}^{24} P_{DHW,hr} = \sum_{hr=1}^{24} P_{HW,hr} \tag{7}$$

where the subscript DHW refers to 'demand hot water' and HW to 'hot water'.

Second, it is assumed that the water heaters can be turned on and off to manage the aggregate demand in each day. Third, it is assumed that the optimal management of the water heater power is that which maximizes the daily load factor (daily mean power/daily maximum power, both aggregated over all apartments) to the greatest extent.

With these assumptions, we first calculated the aggregate hourly power ($P_{aggregate,hr}$) minus the current hourly water heater power ($P_{HW,hr}$) according to Eq. 8 to find the hourly power demand for non-water-heating consumption:

$$P_{aggregate-HW,hr} = P_{aggregate,hr} - P_{HW,hr} \tag{8}$$

Given that the water heating consumption is comparably large relative to other types of consumption for this apartment complex, it is assumed as a first attempt that the hourly aggregate power after water heater demand management can be made constant. Thus,

$$P_{aggregate\ w/DHW,hr} = P_{aggregate-DHW,current,hr} + P_{DHW,hr} = C \tag{9}$$

Solving the system of equations given by Eqns. 7-9 yields the optimal hourly water heater power for each day. It should be noted that if the water heater power isn't sufficient to completely balance the load for each day, then an optimization approach could easily be used to determine the hourly water heater power that maximizes the daily load factor (mean/max).

The water-heater demand management for Pricing Scenario 2 is not about reducing the peaks but shifting power completely to the lowest cost hourly periods. To achieve this best, the hourly water heater power for each day is controlled in order to reduce the daily real time purchase cost. This optimization problem is framed as:

$$\text{Minimize}\left(\sum_{hr=1}^{24} P_{aggregate,DHW,hr} \times cost_{hr}\right) \tag{10}$$

subject to the constraints:

$$\sum_{hr=1}^{24} P_{DHW,hr} = \sum_{hr=1}^{24} P_{HW,hr} \text{ and } P_{DHW,hr} \leq P_{max,unit} \times (\# \, apartments)$$

where $cost_{hr}$ is the hourly RPM cost and $P_{max,unit}$ is the maximum power for each individual water heater (4.5 kW).

Demand-side management reduces the grid energy purchase cost and thus reduces the lower bound for the clean energy fee given by Eq. 5. It also works synergistically with the energy efficiency investments, offering a reduced per kWh price for the generation purchase associated with each measure.

Supply-Side Management

The use of stored solar energy can reduce power purchase by flattening the daily load factor (Pricing Scenario 1) and reducing grid power purchase costs by shifting purchases from the peak cost periods for each day. Here, we consider solar plus storage only after energy efficiency and the water-heater demand management described previously are adopted, as investment in RE and storage is at this time the least cost effective [36]. Additionally, it is assumed that the most beneficial grid purchase scenario for employing solar is associated with power purchase via RPM from the RTO, so only the Pricing Scenario 2 is considered for this. Thus, the daily stored solar energy would be deployed each day during the hour or hours where the real-time prices were highest. It is further assumed that we are using a battery converter instead of an inverter, as the present state of the art offers 95% efficiency at 10% rated power, an improvement of about 7 percentage points over conventional inverters at lower cost, size and weight [37]. Lastly, a 100% depth of discharge is assumed.

Finally, for this study, it is assumed that the daily horizontal solar energy flux for the time period considered (NASA Prediction of Worldwide Energy Resource (POWER) Climatology Resource for Agroclimatology [38]) is used exclusively to provide power during peak power cost periods only, either directly used to support load or stored in a battery, which is then discharged only during the peak cost periods.

The methodology for maximizing the benefit of solar PV for a given solar capacity, *S* (kW), and battery capacity, *B* (kWh), for each day of the year is as follows. Assumed is that hourly demand after implementing energy efficiency measures and water heater demand management, *P*(kW), power purchase price, *C* ($/kW), can be accurately forecast for the next 24 hours. It is also assumed that the battery is fully discharged at the beginning of each day, thus all stored solar energy from the previous day, $Q_{solar,daily}$, is assumed to be utilized in the following day during the highest power cost hours. The maximum storage is equal to the minimum of the maximum battery capacity, *B*, and $Q_{solar,daily}$. Thus,

$$B_{daily} = \min(B, Q_{solar,daily}) \tag{11}$$

This stored energy is deployed to meet power needs at highest cost hours until all stored energy is consumed. The stored energy deployed for each hour, $B_{deployed,hr,}$ in descending order of cost is equal to:

$$B_{deployed,hr} = \max\left[min\left(B_{daily}, \sum_{i=1}^{hr-1} P_i\right), 0\right] \tag{12}$$

where I = 1 corresponds to the hour where the power cost is maximum with P_i the power demand at that hour, i = 2 corresponds to the next most costly hour, etc… Thus in order of descending cost, the hourly grid purchase cost reduction will be equal to:

$$C_{reduced,hr} = C_{hr}\, B_{deployed,hr} \tag{13}$$

The annual grid purchase cost reduction is just the sum of $C_{reduced,hr}$ for all hours in the year.

As is the case for demand-side management, supply-side management reduces the grid energy purchase cost and thus reduces the lower bound for the clean energy fee given by Eq. 5. It also works synergistically with the energy efficiency investments, offering a reduced per kWh price for the generation purchase associated with each measure.

3. Results

Here results are presented for the clean energy fee for each individual energy measure and for the synergistic implementation of all measures. Additionally, results are presented for a synergistic investment in all measures along with water-heater demand management. Finally, results are presented for the clean energy fee needed to support the synergistic collection of all measures and demand- and supply-side management.

3.1 Clean Energy Fee for Individual Energy Efficiency Measures

Table 4 summarizes the economics for each of the individual measures considered for both Power Pricing Schedules. Included in the table are monthly per resident costs/incomes for each measure for retrofit investments for the clean energy utility. Included are monthly per resident costs associated with measure-specific loan payback, the gross profit (e.g., difference between energy sales to residents minus grid purchase costs) associated with the current system, the energy sales attributable to the system currently and after measure adoption were a consumption fee to be retained, the grid purchase cost currently and after adoption of the measure, and the clean energy fee representing the minimum or break-even condition and the clean energy fee associated with equivalent profit for the utility (difference between current sales and grid purchase cost). This table shows clearly that were a consumption-based sales strategy ($/kWh) to be retained, the economic impact of investment by the clean energy utility would be dismal, as each of the energy efficiency measures considered (improved lighting, upgraded refrigerator, water heater, and heat pump) reduces income from energy sales to residents. The clean energy investments are economically advantageous only if a clean energy fee structure is employed. The utility would be able to justify investment in clean energy only if the clean energy fee is set such that a profit can be maintained. In fact, as highlighted, Table 4 shows that the monthly clean energy fee to achieve the same profit for all of the measures, except for the refrigerator and heat pump, is lower than current residential sales price. The results for Pricing Schedule 2 show better economics, with per resident grid purchase costs about 10% less for each measure considered. In this case, the minimum clean energy fee lower than the average monthly energy consumption fee residents are paying.

It should also be noted that the likelihood of the utility to continue charging a residential tariff rate, while purchasing power at a discounted commercial rate is not a situation that will likely be permitted by state utility commissions for the long-term. Thus the future clean energy fee will have to be structured to be somewhere in between the minimum fee (per resident annual loan payment for a given measure + per resident grid purchase cost for a given measure) and the clean energy fee for equal current profit. **Most importantly, the lower bound for this clean energy fee is roughly 1/3 of the cost to residents than they currently are paying.** For nearly all measures considered this minimum fee is less than the current average monthly expenditure by residents for the delivered power.

Table 4. Monthly per resident clean energy economics for individual measures retrofits using current power pricing schedule (Pricing Schedule 1)

		Loan	**Profit**	**Sales**		**Grid Purchase Cost**		**Clean Energy Fee**	
	Measure		**current**	**current**	**post**	**current**	**post**	**min**	**for current profit**
Prcing Schedule 1	LED lighting	$0.00	$9.53	$22.10	$5.53	$13.93	$3.56	$13.93	$23.46
	Energy Star Refrigerator	$4.59	$2.98	$6.97	$4.35	$4.22	$2.65	$8.81	$11.79
	Heat Pump Water Heat.	$5.35	$10.78	$25.08	$8.36	$15.08	$5.16	$20.43	$31.21
	High Eff. Heat Pump	$19.12	$9.30	$28.27	$13.30	$14.20	$8.84	$33.32	$42.62
Prcing Schedule 2	LED lighting	$0.00	$9.53	$22.10	$5.53	$10.93	$2.80	$10.93	$20.46
	Energy Star Refrigerator	$4.59	$2.98	$6.97	$4.35	$3.36	$2.11	$7.95	$10.93
	Heat Pump Water Heat.	$5.35	$10.78	$25.08	$8.36	$11.99	$4.10	$17.34	$28.12
	High Eff. Heat Pump	$19.12	$9.30	$28.27	$13.30	$10.69	$6.65	$29.81	$39.11

3.2 Synergistic Energy Efficiency Investment with Water Heater Demand Management and Solar-PV Supply Side Management

The value of managing water heat consumption and solar PV/Battery supply-side management was next evaluated for only Power Pricing Schedule 2, as this pricing schedule was shown in the previous section to be best. Figure 7 illustrates the value of water heating demand-side management pre-retrofit. Shown is the monthly load factor [mean(power) / max(power)] for the time period from 6-9-2013 to 6-9-2014 for the actual data and for the case with optimal water heater power control. It is apparent from this figure how big the impact of water heater control is on the load factor and thus upon the current monthly demand based pricing depicted in Figure 4a. The results show that that the grid purchase cost can be reduced by approximately 1/3.

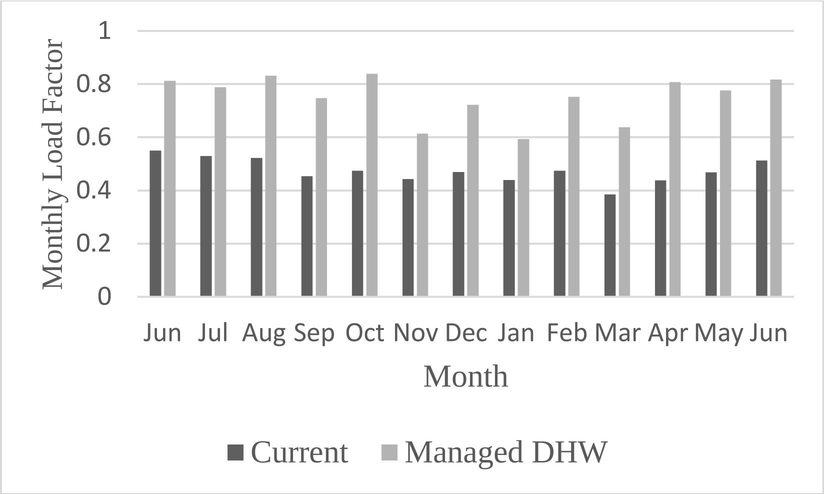


Figure 7. Monthly load factor for current situation and for optimally managed DHW

A parametric evaluation of both solar PV and battery capacity, assuming that all efficiency investments and water heater demand-side management have already been implemented, was used to find a near-optimal packaging of the solar PV capacity and battery size. Considered here is only one of these optimal cases, with a solar PV area of approximately 500 m^2 and a battery capacity of 475 kWh.

Table 5 summarizes the results for a synergistic *packaging* of all retrofit clean energy measures considered previously in Section 3.1 along with both water heater demand-side management and water heater demand-side management and solar PV/Battery supply-side management. This table shows clearly that current energy sales are much greater than the minimum clean energy pricing proposed for both cases. Thus, there is real opportunity to invest in clean energy and realize profit, while also reducing costs for residents. Additionally, it is obvious, in comparing the clean energy fee for current profit (last column) to the current sales, that the clean energy fee for both cases is only slightly higher than what residents are now paying. Thus, there is even a possibility of lowering residents' costs NOW while investing in deep energy reductions. In fact, the measures considered here respectively yield grid energy and carbon reduction of 42.3% and 54.45%.

Table 5. Clean energy economics for synergistic measures of retrofit investments with water heater demand-side management and water heater demand-side management and solar PV/Battery supply-side management for Pricing Scenario 2

	Loan	**Profit**	**Energy Sales to Residents**		**Grid Purchase Cost**		**Clean Energy Fee**	
Measure		**current**	**current**	**post**	**current**	**post**	**min**	**for current profit**
Synergistic retrofit investments w/ demand-side management	$29.07	$40.68	$94.63	$54.66	$45.83	$34.81	$63.88	$104.57
Synergistic retrofit investments w/	$41.35	$40.68	$94.63	$54.66	$45.83	$19.58	$60.93	$101.81

demand and supply-side management								

4. Conclusions and Recommendations

This study utilized a case study of a multifamily building in the Midwest of the U.S. to show that deep energy and carbon reduction (> 50%) could be achieved in an economically beneficial way were a clean energy utility for multifamily residences to: finance investment in energy efficiency, renewable energy, and storage; manage demand to reduce energy purchase cost; and engage in supply-side response management to optimize the economic impact of solar PV/Battery storage; recovering investments and costs for services through a per resident clean energy fee rather than a per consumption fee. The per resident clean energy fee would minimally offset loan payback costs for all investments and grid purchase costs for the facility distributed uniformly to all residents. The split incentive roadblock to EERE investment is overcome.

Critical to the success of such a utility is investment in unit level measurement of power and water consumption in order to gauge the value of investments in both energy reduction and impact on demand costs. Additionally this information is necessary for optimizing the economic value of both demand-side and supply-side management.

Also important here is that while the economic value for this study has focused on the clean energy utility and the residents, the reality is that the economics of this approach is almost certain to be better in many U.S. states, where state incentives for renewable energy and storage exist, unlike that present in the state considered. Further, were the EPA social cost of carbon, about $37/ton, to be considered, the economic argument would be even stronger. Finally, consideration of energy price escalation would also yield improved economic value for this model.

Additionally, the reality is that the model posed isn’t cost neutral for facility owners. It offers them significant value. First, they benefit from the investments which increase the value of the facility without any out of pocket expense on their part. Secondly, as a result of the investments, they would be positioned to market their facility as a green residence; something that would certainly attract potential residents, thus increasing occupancy, or permit an increase in rental fees.

The energy and carbon reduction from this model may in fact be under-estimated. For example, if residences are provided real-time feedback on their energy use, consumption decreases, on average. Additionally, the clean energy utility might incentivize residences to save energy through behavior changes, providing a shared benefit to the utility and residence.

Finally, the results from this study elucidate the possibility of a non-profit or public utility serving the role of a clean energy utility. If the profit requirement is eliminated, then even the case considered with EERE and demand-side and supply-side management packaged together– realizing 54.45% grid energy reduction, yields much lower cost to residences than their current costs.

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