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TIME-VARYING VALUE OF ENERGY EFFICIENCY IN MICHIGAN[1]

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In December 2016, the Michigan Legislature passed new laws (SB 341 and 342) that require the Public Service Commission (PSC) to create regulations for integrated resource planning (IRP) and determine the potential of energy waste reduction resources to meet electricity needs. Following stakeholder engagement meetings, the PSC requested technical assistance from Berkeley Lab to better understand how to account for the time-varying value of electricity savings in IRP and demand-side management (DSM) planning in Michigan. Working collaboratively with the PSC, Consumers Energy and DTE Energy, Berkeley Lab calculated the time-varying value of electricity savings for five energy efficiency measures in the utilities' service areas.

Quantifying the time-varying value of energy efficiency is necessary to properly account for all of its benefits and costs and to identify and implement efficiency resources that contribute to a low-cost, reliable electric system (Mims et al. 2017; Boomhower and Davis 2016). Historically, most quantification of the benefits of efficiency have focused largely on the economic value of annual reductions in energy use. Due to the lack of statistically representative, metered data on end-use load shapes in Michigan (i.e., the hourly or seasonal timing of electricity savings), the ability to confidently characterize the time-varying value of energy efficiency savings in the state, especially for weather-sensitive measures such as central air conditioning, is limited.

Based on our analysis of data from Consumers Energy and DTE Energy, we conclude that: (1) overall, the ratio of the total utility system value of energy savings to their energy-related value in Michigan aligns with other states with similar system load shapes; (2) end-use load shape research that is specific to Michigan would enable more accurate analysis of the time-varying value of efficiency; (3) until such time that statistically representative, metered data on end-use load shapes in Michigan are available, data from regions with similar energy consumption characteristics should be considered for adoption (e.g., we used Pacific Northwest end-use load shapes in our analysis because they are based on metered data and are very similar to the end-use load shapes for some measures from the Electric Power Research Institute (EPRI) End Use Load Shape Library that are applicable to Michigan); and (4) an investigation of all value streams for energy efficiency (e.g., avoided risk and air emissions values) in Michigan will help avoid undervaluing this resource.

Still, electric utilities in Michigan can take advantage of opportunities to incorporate the time-varying value of efficiency into their planning. For example, end-use load research and hourly valuation of efficiency savings can be used for a variety of electricity planning functions, including load forecasting, DSM, demand-side evaluation, capacity planning, long-term resource planning, renewable energy integration, assessing potential grid modernization investments, establishing rates and pricing, and customer service (KEMA 2012). In addition, accurately calculating the time-varying value of efficiency may help energy efficiency program administrators prioritize existing offerings, set incentive or rebate levels that reflect the full value of efficiency, and design new programs.

[1] This work builds on Berkeley Lab's prior analysis that calculated the time-varying value of electricity savings for the same five energy efficiency measures in four regions of the country. See https://emp.lbl.gov/publications/time-varying-value-electric-energy.

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1. INTRODUCTION

Energy efficiency resources can reduce both energy consumption and peak demand for electricity systems. This brief seeks to advance consideration of the value of energy efficiency during times of peak electricity demand and high electricity prices in applications such as efficiency potential studies, DSM plans and IRP processes in Michigan. Using Consumers Energy and DTE Energy's load shape data and electric avoided costs, this study quantifies the time-varying value of energy and demand impacts for five types of electric efficiency measures in Michigan.

Most energy efficiency measures produce energy savings that vary over the course of a year. The value of the hourly electricity savings also varies over the course of a year because the avoided cost of generating, transmitting, and distributing electricity during peak demand periods may be significantly higher than during off-peak, or lower load, hours. To properly calculate the value of electricity savings to the utility system, it is necessary to account for variations in hourly energy savings, hourly avoided energy costs, and potential deferral of capital investment in new generation, transmission, and distribution infrastructure, among other factors. Efficiency also can reduce economic risk, resulting in an avoided risk mitigation cost. For example, future generating fuel prices might be higher or more volatile than forecast. In states with renewable portfolio standards (RPS) in place, and where such standards are a function of annual retail sales (or fraction of installed capacity), the value of avoided investments in new renewable resources, when utility system costs for those resources exceed alternative resource costs, should explicitly be included. Similarly, avoided pollutant emissions should be considered on a time-sensitive basis. Finally, centrally-organized wholesale electricity markets typically account for the market price impacts of reduced energy and capacity demands due to energy efficiency or demand response programs, or both, referred to as *demand reduction-induced price effects* (DRIPE).[3]

Using accurate end-use load shapes or savings shapes and including values that are often missing or not available, such as deferred or avoided transmission and distribution investments, may result in additional or different energy efficiency measures being promoted and installed to reduce electricity system peak or increase reliability. Establishing protocols for consistent methods and procedures for developing end-use load shapes and load shapes of efficiency measures may help ensure that accurate data is being used to estimate peak demand reductions from energy efficiency programs. In addition, this information may help program administrators prioritize existing efficiency offerings, set incentive or rebate levels that reflect the full value of efficiency, or design new programs.

2. ENERGY EFFICIENCY MEASURES USED IN THE ANALYSIS

We selected five electric efficiency measures to illustrate time-varying impacts, based on when the measures save energy. Specifically, the measures illustrate the difference in value for winter and summer peaking electricity systems and coincidence (or lack of coincidence) with peak demands.

- **Exit sign:** This is representative of measures that operate all hours of the year, with uniform (flat) savings across all hours of the year. This load shape does not vary across geographic location, so its

[3] DRIPE refers to the reduction in wholesale market prices for energy and/or capacity expected from reductions in the quantities of energy and/or capacity required from those markets during a given period due to the impact of efficiency and/or demand response programs. Thus, DRIPE is a measure of the value of efficiency received by all retail customers during a given period in the form of expected reductions in wholesale prices. The avoided cost value of DRIPE during a given time period is equal to the projected impact on the wholesale market price during that period, expressed as a dollar per unit of energy, multiplied by the quantity of energy purchased at rates or prices tied directly to that given market price. (Source: Avoided Energy Supply Costs in New England: 2015 Report, Prepared for the Avoided-Energy-Supply-Component (AESC) Study Group. March 27, 2015 (Revised April 3, 2015). In very simplified terms, DRIPE is the value of reducing the cost of supplying electricity in a centrally-organized wholesale electricity market as a result of placing lower demands on the market. Although Michigan utilities participate in MISO, no estimate of this effect was available, so we assumed this value to be zero for the purpose of this analysis.

value is not affected by differences in end-use load shape by location.

- **Residential electric high-efficiency water heating and air conditioning:** These are representative of measures that are highly coincident with peak demands (e.g., water heating in the Pacific Northwest (PNW) air conditioning in the summer in other U.S. locations).
- **Residential lighting:** These are representative of measures that may contribute differing amounts toward peak demands depending upon the season and location. They are often the largest share of savings in energy efficiency programs.
- **Commercial lighting:** These are representative of measures that are similar across all locations and highly coincident with peak demands. They typically represent a significant share of efficiency program savings.

3. MICHIGAN ELECTRICITY SYSTEM SHAPE

Figure 1 shows the annual monthly system load shape for Michigan. The vertical axis shows the peak monthly demand as a percent of the annual system peak month's demand. The state's electricity system peaks in the summer months (i.e., in July or August reaches 100 percent of peak demand), driven primarily by air conditioning loads. The summer peak demands for Michigan are significantly higher than winter peaks. The electricity system load shape is an important input to the calculation of the time-varying value of electricity savings because energy savings that occur during or near times of system peak demand reduce or defer the need for investments, while those that occur primarily during "off-peak" hours are less valuable.

Figure 1. Michigan monthly system load shape

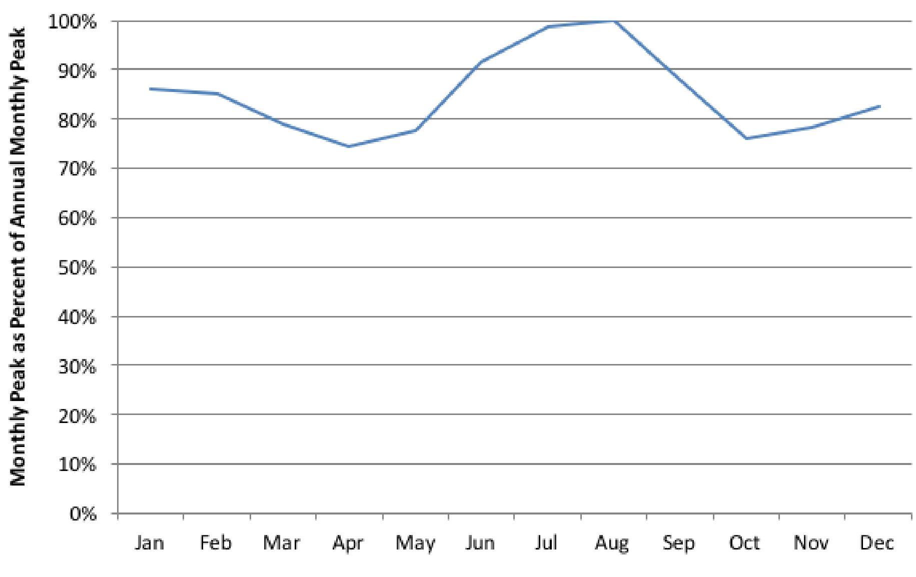
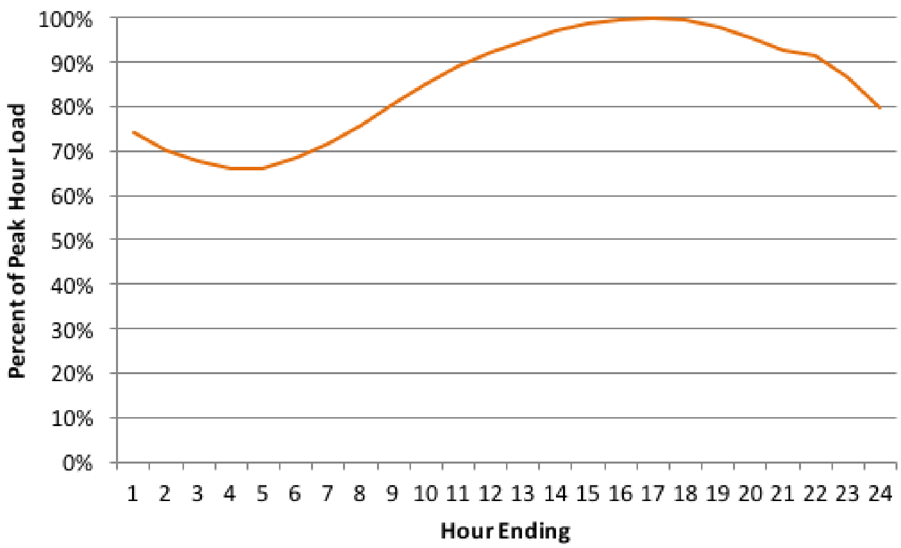


Figure 2 shows the typical daily summer load shape for Michigan. The horizontal axis plots time of day, with hour 1 equal to the hour between midnight and 1 AM. The vertical axis plots the percent of maximum (i.e., peak) hourly demand that occurs at each hour of the day. For example, Figure 2 shows that the peak hour demand (i.e., when the percent of peak hour load equals 100 percent) on a summer day in Michigan is at hours 17 and 18, and that at hours 4 and 5 system loads are only 66 percent (i.e., the percent of peak hour load equals 66 percent) of the day's peak demand.

Figure 2. Hourly load shape on a typical summer day for Michigan



4. Approach to Calculating the Time-Varying Value of Efficiency

There are two general approaches for capturing the time-varying value of electricity savings. Method 1 is the most common. It uses daily or seasonal load shape data, or both, to allocate energy savings into peak periods and off-peak periods and uses coincidence factors[4] (see text box below) to estimate peak impacts. Method 2 uses annual hourly data for both energy savings and avoided costs (Stern 2017).[5] Both approaches require data on the load shape of efficiency measure savings, utility system load shapes, and utility system avoided costs. The primary differences between the two methods are the fidelity or granularity of their data requirements and the method used to determine peak reduction impacts of efficiency measures. Table 1 describes the method, data sources, and origin of the data that Berkeley Lab used to calculate the time-varying value of efficiency.

How are diversity factors and coincidence factors used to estimate utility system peak reductions from energy efficiency savings?

A *diversity factor* accounts for the fact than an individual efficiency measure may save a certain amount of demand, but across an entire program the installed measure does not operate at the same time in all of the locations. For example, if a maximum of six of 10 installed light-emitting diodes (LEDs) are on at any given time, the diversity factor for this measure is 0.6. The product of the diversity factor and the maximum demand reduction from all installations is referred to as the *diversified demand*.

A *coincidence factor* accounts for whether an end-use efficiency measure is reducing use at the same time as the electricity system peak. The diversified demand for an end use may not align exactly with the utility system peak. For example, if only two of the six installed LEDs are typically on at the time of the system peak (their use occurs simultaneously with the system peak), the measure's savings have a coincidence factor of 2/6 or 0.33. Thus, the peak demand savings for an efficiency measure is calculated as the product of the coincidence factor, diversity factor and maximum demand at individual sites.

[4] Stern (2017) discusses the variation in definition of coincidence factor.

[5] See Stern (2017) for a detailed explanation of alternative approaches that can be used to estimate peak energy savings. Some of these approaches do not rely on end-use metered data.

Table 1. Description of use of Method 2 and data used by Berkeley Lab for calculating the time-varying value of energy efficiency

Description of Method	Data Sources	Origin of Data Source
Annual hourly energy savings are multiplied by the levelized value of hourly avoided energy cost data to determine the time-varying value of energy.	• Annual energy savings for all measures normalized to 1,000 kWh (1 MWh)/year • DSMore hourly load shape • Avoided hourly energy cost based on forecast of future MISO energy prices	DSMore hourly load data and hourly avoided cost provided by utilities to Berkeley Lab[6]
The time-varying value of capacity savings for each end use and its savings during the hour that is coincident with the system peak hour (hour ending 18) are calculated based on the DSMore load shapes. These peak savings are multiplied by the levelized avoided cost in $/MW-year for capacity ancillary services and deferred transmission and distribution. Values are then converted to a levelized cost/MWh.	• System hourly load shape (average 2014-16)[7] • DSMore load shape • Calculated coincident peak savings • Utility forecast of avoided capacity, ancillary services and transmission/ distribution costs	Provided by utilities to Berkeley Lab

This analysis focused primarily on the utility system avoided cost resulting from energy and capacity savings.[8] Avoided cost includes avoided investments in energy generation (including both fuel and capital cost), avoided capital investments in peak capacity, deferred investments in transmission and distribution capacity, and reduced requirements for additional ancillary services such as spinning and operating reserves.

[6] Forecast of future hourly energy prices are assumed to be the average of Consumers Energy and DTE Energy.
[7] The avoided costs for capacity-related resources (e.g., generating capacity, transmission, distribution, and ancillary services) were not available *at an hourly* level from the utilities. However, the utilities were able to provide forecast for these capacity-related costs on an annualized basis (i.e., $/kW-year).
[8] This analysis focuses on the value to the electric utility system of energy efficiency savings. If non-energy benefits (NEBs) are constant throughout the day or year, they simply add a uniform value across all hours. However, if the value of a NEB varies significantly with time of day or season, its time-varying value could also be added to the time-varying value of utility system benefits. See Lazar and Colburn (2013) for a more extensive treatment of both utility system and non-utility system benefits of energy efficiency savings.

Depending on the jurisdiction and market structure, other avoided utility system costs might include avoided cost of compliance with air emissions regulations,[9] avoided RPS compliance costs,[10] risk mitigation costs,[11] and DRIPE. These costs were assumed to be zero in Michigan, which may undervalue energy efficiency.

The following is a summary of the avoided costs used in this analysis:

- **Energy-related cost:** Levelized cost by time segment (e.g., hourly, by peak or off-peak period) of additional energy (kilowatt-hour, kWh) supplies.[12] In a vertically integrated utility system, these costs are typically represented by the levelized cost of energy from a new power plant, including fuel, capital, fixed operation and maintenance cost, and periodic capital replacement cost. In centrally-organized wholesale electricity markets (e.g., MISO, PJM, ISO-NE) and in areas where utilities have access to wholesale electricity markets, avoided energy costs are typically represented by the forecast of future market prices for energy.
- **Generation capacity-related cost:** Levelized cost by time segment ($/kWh) or present value cost by time segment ($/kW-yr) of deferred peaking capacity, including capital, fixed operation and maintenance cost, and periodic capital replacement cost. Depending on the location and avoided cost methodology, this value may be determined by a proxy generating unit or the marginal capacity value of the system.
- **Ancillary services:** Reduced requirements for spinning and operating reserve capacity, if not captured in generation capacity cost ($/kW-yr).
- **Transmission capacity-related cost:** Levelized cost by time segment ($/kWh) or present value cost by time segment ($/kW-yr) of transmission system expansion avoided or deferred as a result of peak demand savings.
- **Distribution capacity-related cost**: Levelized cost by time segment ($/kWh) or present value cost ($/kW-yr) of distribution system expansion avoided or deferred as a result of peak demand savings.

Table 2 shows the values for the avoided cost inputs used to calculate the time-varying value of energy efficiency for Michigan. To facilitate comparison, we assumed all measures save 1,000 kWh per year (1 megawatt-hour, MWh) so that the difference in value among various types of efficiency measures is due solely to their time-varying impacts, and not a result of variations in the absolute magnitude of their annual energy

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[9] This value can be the market value in states that have established carbon prices (e.g., California and the Regional Greenhouse Gas Initiative that includes Massachusetts), or it may represent a "virtual" price used to reflect public policy. Another approach to value avoided air emissions is to use the cost of emissions control equipment at electricity generating plants. Energy efficiency displaces emissions of nitrogen oxide, sulfur dioxide, mercury, and particulate matter. For Michigan, these values were assumed to be zero for the purpose of this analysis.

[10] If an RPS is based on supplying at least a minimum amount of retail sales with renewable resources, energy efficiency reduces the amount of retail sales. Thus, the amount of renewable resources required to satisfy a utility's RPS obligations will be lower. Michigan has an RPS that requires 15 percent of retail sales to be met using renewable resource by 2021. Thus, each megawatt-hour of energy savings means that utilities can scale back their acquisition of renewable resources by 15 percent of a megawatt-hour, or 150 kWh. The value of reduced RPS compliance cost is determined by the difference between the cost of additional renewable resources and the cost of energy that could be acquired from other resources. The value of reduced RPS compliance (i.e., avoided cost) in Michigan is projected to be *de minimus* because the Michigan Public Service Commission expects the cost of renewable resources to be less than the cost of long-term supplies of other supply-side resources.

[11] Efficiency also can reduce economic risk. For example, future generating fuel prices might be higher or more volatile than forecast. For this analysis, the estimated risk mitigation value of efficiency is assumed to be zero.

[12] Levelized cost of energy is "the per kilowatt-hour cost (in discounted real dollars) of building and operating a generating plant over an assumed financial life and duty cycle." Energy Information Administration 2017. Use of levelized cost allows for comparisons in the cost or value of energy resources which vary in size and lifetime. We converted all energy- and capacity-related levelized avoided costs specified in kW-year to levelized cost per kWh based on assumed site annual savings of 1,000 kWh (1 MWh) distributed across each hour (or season), based on load shape of the specific end use. For example, for the exit sign (flat) load shape, savings in each hour were 0.114 kWh (1,000 kWh/8,760 hours). A levelized cost of $100 kW-yr translates into a levelized value of $0.0114/kWh for this load shape.

savings. Similarly, we assume that all measures remain in service for 15 years so that all measures are compared to the same stream of avoided costs. Since the value of avoided energy cost not only varies by load shape, but potentially differs for each hour of the year and each year over the 15-year measure life used, the table cannot show all of the values. However, Section 7 (Results) shows the levelized value of savings across all hours and years by end-use load shape.

Finally, as noted above, some regions include an avoided cost of compliance with air emissions regulations, risk mitigation costs, and DRIPE. These costs were assumed to be zero in Michigan, which may undervalue energy efficiency. Prior analysis by Berkeley Lab (Mims et al. 2017) found that in states where avoided cost includes a value for the risk mitigation benefits of energy efficiency, the total value of savings increased by 3-5 percent, depending on load shape. Including DRIPE also increased the value of savings, by about 5 percent. For those jurisdictions which include a value for reduced carbon dioxide emissions, the total value of energy savings increased significantly — by 6-13 percent in California, 13-28 percent in Massachusetts, and 32-52 percent in the Pacific Northwest.

Table 2. Time-varying value of energy savings: Input assumptions for Michigan avoided costs[13]

Input Assumption	Value
Real Discount Rate*	3.88%
Expected Measure Life	15 years
Annual Savings (Normalized for all measures)	1,000 kWh (1 MWh)
System Losses	7.08%
Levelized Avoided Energy Cost	Varies by load shape
Levelized Avoided Capacity Cost (2016$)	$71.50/kW-yr
Levelized Avoided Transmission and Distribution Cost (2016$)	$80/kW-yr
Levelized Avoided Ancillary Service Cost (2016$)	$3.34/kW-yr

*Based on nominal discount rate of 6.37% and inflation rate of 2.4%

5. Consumers Energy and DTE Energy Efficiency Modeling

Historically, the utilities in Michigan have considered the value of efficiency and magnitude of the energy and demand savings of efficiency measures in their energy waste reduction programs (demand-side management programs) as required by Public Act 295. Utilities in Michigan use the utility system resource cost test, which defines cost-effective as "if, on a life cycle basis, the total avoided supply-side costs to the provider, including representative values for electricity or natural gas supply, transmission, distribution and other associated cost, are greater than the total costs to the provider of administering and delivering the energy optimization program, including net costs for any provider incentives paid by customers and capitalized costs recovered."[14]

[13] The real discount rate, system losses, levelized avoided energy cost, levelized avoided capacity cost, levelized avoided transmission and distribution cost and levelized avoided ancillary service cost were provided for Consumers Energy and DTE Energy by Morgan Marketing Partners.
[14] The text for Public Act 295 is available at: http://www.legislature.mi.gov/documents/2007-2008/publicact/pdf/2008-PA-0295.pdf

Consumers Energy and DTE Energy both use the DSMore[15] model to calculate the value and quantity of electricity savings. DSMore uses the energy and capacity savings values from the Michigan Energy Measures Database (MEMD)[16] and a forecast of Mid-Continent Independent System Operator (MISO) energy prices to determine the economic value of efficiency measures. Table 3 displays the method and data used to determine value and magnitude of energy efficiency for the utilities, based on our review of Consumers Energy and DTE Energy's data. A comparison of Table 1 and Table 3 shows the difference in data and approach currently used by Consumers Energy and DTE Energy in their energy efficiency modeling, and our suggested approach for calculating the time-varying value of efficiency.

Table 3. Consumers Energy and DTE Energy's methods and data for modeling energy and capacity savings from efficiency

Method Used	Description of Method	Data Sources	Origin of Data Source
Method 1	Capacity savings are the peak savings provided in the MEMD or are derived from the coincidence factors provided in the MEMD. These peak savings are multiplied by the levelized avoided cost in $/MW-year for capacity ancillary services and deferred transmission and distribution. These values are then converted to a levelized cost/MWh.	• MEMD energy savings • MEMD capacity savings and/or coincidence factors • Utility forecast of avoided capacity, ancillary services and transmission/distribution costs	MEMD, MISO & utilities
Method 2	Annual hourly energy savings are multiplied by the levelized value of hourly avoided energy cost data.	• MEMD annual energy savings specific to each measure • DSMore hourly load shape • Avoided energy cost based on forecast of MISO energy prices specific to each utility	MEMD, MISO & utilities

6. Comparison of Data

As discussed above, Consumers Energy and DTE Energy both use DSMore to calculate the value and quantity of electricity savings. DSMore uses the energy and capacity savings values from the MEMD and a forecast of MISO energy prices to determine the economic value of efficiency measures. Berkeley Lab began the time-varying value of efficiency analysis with the DSMore data, but after modeling the end-use load shapes,[17] realized that using the DSMore end-use load shapes may under- or over-value efficiency (e.g., DSMore load shapes are scaled from whole house demand in Michigan, rather than an individual end-use), as discussed in Section 7. Subsequently, we reviewed metered data from the Pacific Northwest and simulated data applicable to Michigan to attempt to identify more accurate energy and capacity savings data from the efficiency measures to calculate the time-varying value of efficiency.

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[15] DSMore is a commercially available model employed by both Consumers Energy and DTE Energy to determine the hourly value of energy savings for their demand-side management plans. See http://www.integralanalytics.com/products-and-services/dsm-planning-and-evaluation/dsmore.aspx.

[16] The MEMD is available at: http://www.michigan.gov/mpsc/0,4639,7-159-52495_55129---,00.html

[17] Generally, availability of publicly available end-use load shapes and energy savings shapes in the United States is very limited. See James and Clement 2016.

We used metered data from the Pacific Northwest in the analysis for several reasons. First, the Pacific Northwest end-use load shapes are based on metered data, which are more robust than simulated data.[18] Second, despite Michigan's warm summers and cold winters, the end-use load shapes for the Pacific Northwest are very similar to the end-use load shapes for residential air-conditioning and residential water heating measures from the EPRI End Use Load Shape Library[19] that are applicable to Michigan (see Appendix for more detail on residential air-conditioning).[20] Finally, the Pacific Northwest is at approximately the same latitude as Michigan, so it experiences similar hours of daylight across the year. One would expect that the pattern and timing of residential lighting use would also be similar. Therefore, we carried out a second set of time-varying value calculations, using identical inputs and methods, but substituting metered load shapes from the Pacific Northwest for the DSMore load shape and MEMD coincidence factors (discussed in Section 7).

End-Use Load Shapes

Reviewing the Michigan utilities end-use load shapes (from DSMore with MEMD coincidence factors) revealed that three of them differed significantly from end-use load shapes derived from metering studies conducted in the Pacific Northwest.[21] Figures 3 through 5 show the end-use load shapes for residential interior lighting, residential water heating, and residential central air conditioning from DSMore and those obtained from metered data in the Pacific Northwest.

Figure 3 shows the summer residential lighting load shape used in efficiency program planning by Consumers Energy and DTE Energy in blue (DSMore) and from metered data in the Pacific Northwest in red. The horizontal axis plots time of day with hour 1 equal to the hour between midnight and 1 AM. The vertical axis plots the percent of maximum (i.e., peak) hourly demand that occurs at each hour of the day. The metered data from the Pacific Northwest is from the Residential Building Survey Assessment (RBSA).[22] It is a traditional residential lighting load shape that ramps up as people wake up, declines through the day while people are at work, and peaks in the evening when people return home and the sun sets.

Figure 3 illustrates two concepts. First, focusing on the metered data from the Pacific Northwest, the influence of longer daylight hours during the summer season can be seen in the residential lighting load shape. The demand for residential lighting on a peak summer day does not occur until much later in the day than the daily peak, with maximum demand occurring between hour 21 and hour 22. Indeed, throughout most of the day, residential lighting loads operate at or below 40 percent of peak daily demands. Therefore, improving the efficiency of residential lighting does not significantly alter utility system summer peak day demand, but does provide significant energy savings. Second, Figure 3 shows that the DSMore end-use load shape for interior lighting in Michigan has a very narrow operating schedule, while the metered data from the Pacific Northwest indicates that some lighting occurs throughout all hours of the day, as one would expect in Michigan as well.

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[18] The work built on prior analysis where Berkeley Lab calculated the time-varying value of electricity savings for the same five energy efficiency measures in four regions of the country. See https://emp.lbl.gov/publications/time-varying-value-electric-energy. The report discusses in part the importance of using metered data. The Appendix of this brief also has more detail on simulated and metered data.

[19] Comparisons of daily commercial and residential end use load shapes based on metered data can be done by electric reliability area on the EPRI's End Use Load Shape Library website. Available at http://loadshape.epri.com/enduse.

[20] Water demand is driven by occupancy, so as might be expected, its pattern of energy use is quite similar across all locations for which metered data is available. The magnitude of residential air conditioning load varies considerably across the country, metered data reveal that the daily shape of this end-use also follows as similar pattern across a wide range of locations. See Appendix for more detail.

[21] In the late 1980s the Bonneville Power Administration metered approximately 500 single-family homes and 80 commercial buildings at the end use level for a period of three years in its End Use and Consumer Assessment Project (ELCAP). More recently (2012), the Northwest Energy Efficiency Alliance metered approximately 100 single-family residences at the end use level for a period of 18 months in its Residential Building Stock Assessment (RBSA) project. The RBSA metered homes were a statistically representative sample of a subset of 1,400 single family residences. The residences were randomly selected to determine regional housing characteristics. The RBSA lighting load shapes are based on metering nearly 1,200 individual lighting fixtures for over 18 months. See Berkeley Lab's time-varying value of efficiency report for a detailed description of these projects.

[22] http://neea.org/resource-center/regional-data-resources

Figure 3. DSMore and metered Pacific Northwest load shapes for residential lighting

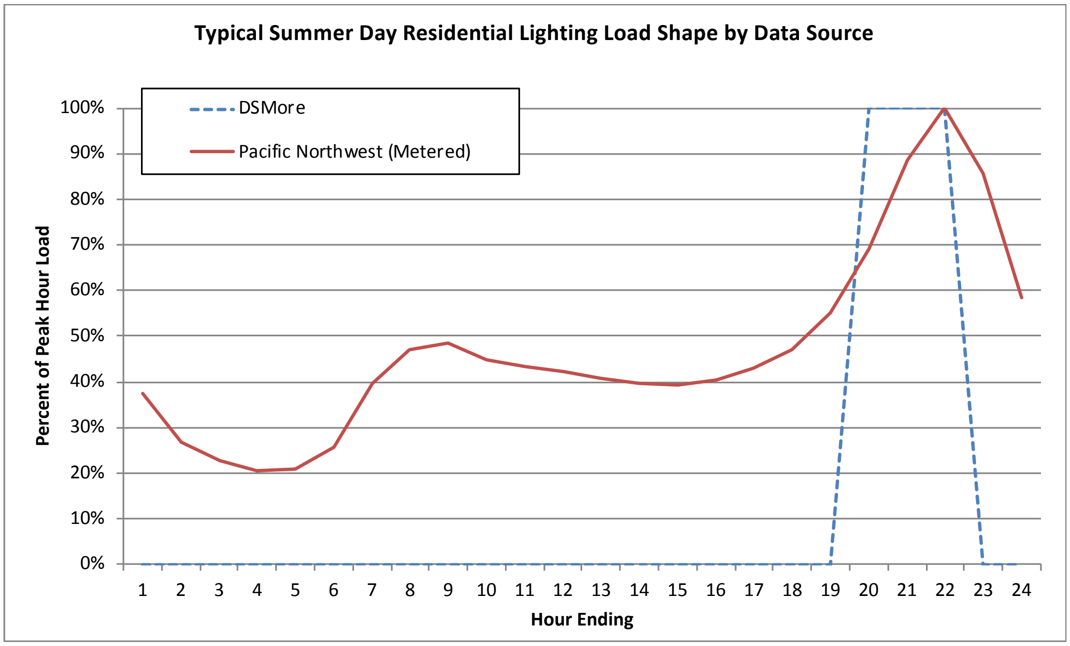


Figure 4 shows residential water heating end-use load shapes. Similar to Figure 3, the data from the Pacific Northwest is from RBSA and follows a more traditional load shape that ramps up as people wake up, declines through the day while people are at work, and peaks in the evening when people return home.

In Figure 4, the DSMore load shapes are scaled from whole house demand in Michigan, rather than an individual end use. Use of this approach may result in the overstatement of both the energy and capacity benefits of residential water heating savings (discussed more in Section 7). The DSMore load shape for residential water heating shows significantly greater use in the afternoon and evening hours. Figure 4 shows that based on metered data from the Pacific Northwest, water heating use declines throughout the afternoon while DSMore's residential water heating load shape shows demand increasing during the afternoon hours, peaking around hour ending 18 (which is also the time of Michigan's system peak). Assuming the Pacific Northwest metered data is illustrative of hot water consumption patterns in Michigan, the summer coincident peak demand reduction impact of residential water heating savings is about 30 percent less than estimated using the DSMore load shape for this end use.

The daily summer *peak* demands for residential water heating using the metered data from the Pacific Northwest shows that its peak does not align with the summer peak *hourly* demand for Michigan. This can be seen by observing Figure 2 (Michigan electricity system shape) where the peak hourly demand in the summer occurs between hour 17 and hour 18. In contrast, the peak demand for residential water heating in the Pacific Northwest (and in other regions explored in prior analysis) occur during the summer occurs between hour 8 and hour 9.[23] Figure 4 illustrates that DSMore's representation of residential water heating demand would make it appear to be a larger factor in creating peak demand in Michigan than it may actually be.

[23] Mims et al., 2017.

Figure 4. DSMore and metered Pacific Northwest load shapes for residential water heating

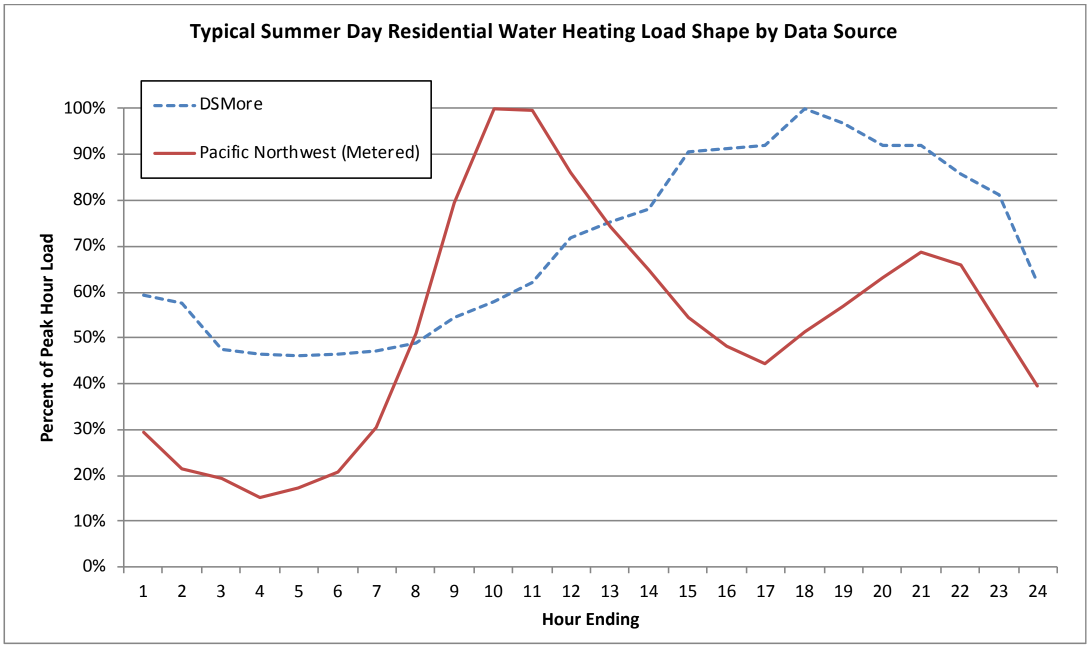
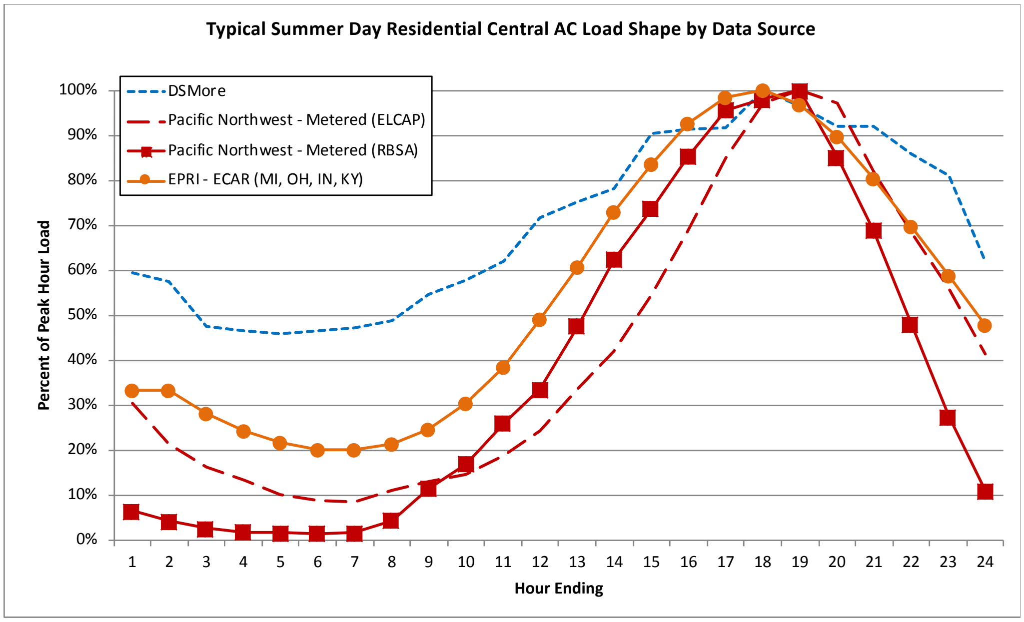


Figure 5 shows residential air-conditioning end-use load shapes from DSMore, the Pacific Northwest and EPRI. The end-use load shapes from the Pacific Northwest are from RBSA and the End-Use Load Consumer Assessment Program (ELCAP)[24], and increase beginning at hour ending 9, reaching its maximum around hour ending 19. The EPRI data, from the Eastern Central Area Reliability Cooperation Agreement (ECAR),[25] which included Michigan, Ohio, Indiana, and Kentucky, is more similar to the Pacific Northwest shape than the DSMore data. For more information on the similarity between residential air-conditioning load shapes for Michigan cities and the Pacific Northwest and EPRI, see Figure A-1 in the Appendix.

In Figure 5, the DSMore load shapes are scaled from whole house demand in Michigan, rather than an individual end use. In contrast to residential water heating, residential air conditioning loads are a primary contributor to the daily summer peak loads for the Michigan electricity system. The DSMore proxy for air-conditioning, represented by whole-home electricity consumption in Michigan, peaks at hour ending 18. As Figure 2 (Michigan electricity system shape) shows, the Michigan electricity system peaks at hours 17 and 18. Thus, the DSMore, metered Pacific Northwest and EPRI load shapes for residential air-conditioning demands are coincident with the utility system peak demands.

[24] https://elcap.nwcouncil.org/
[25] ECAR was replaced by ReliabilityFirst, a regional council of the North American Electric Reliability Corporation in 2006.

Figure 5. DSMore, metered Pacific Northwest and EPRI regional load shapes for residential central air-conditioning



*ECAR was replaced by ReliabilityFirst in 2006. Data are from the EPRI Load Shape Library.

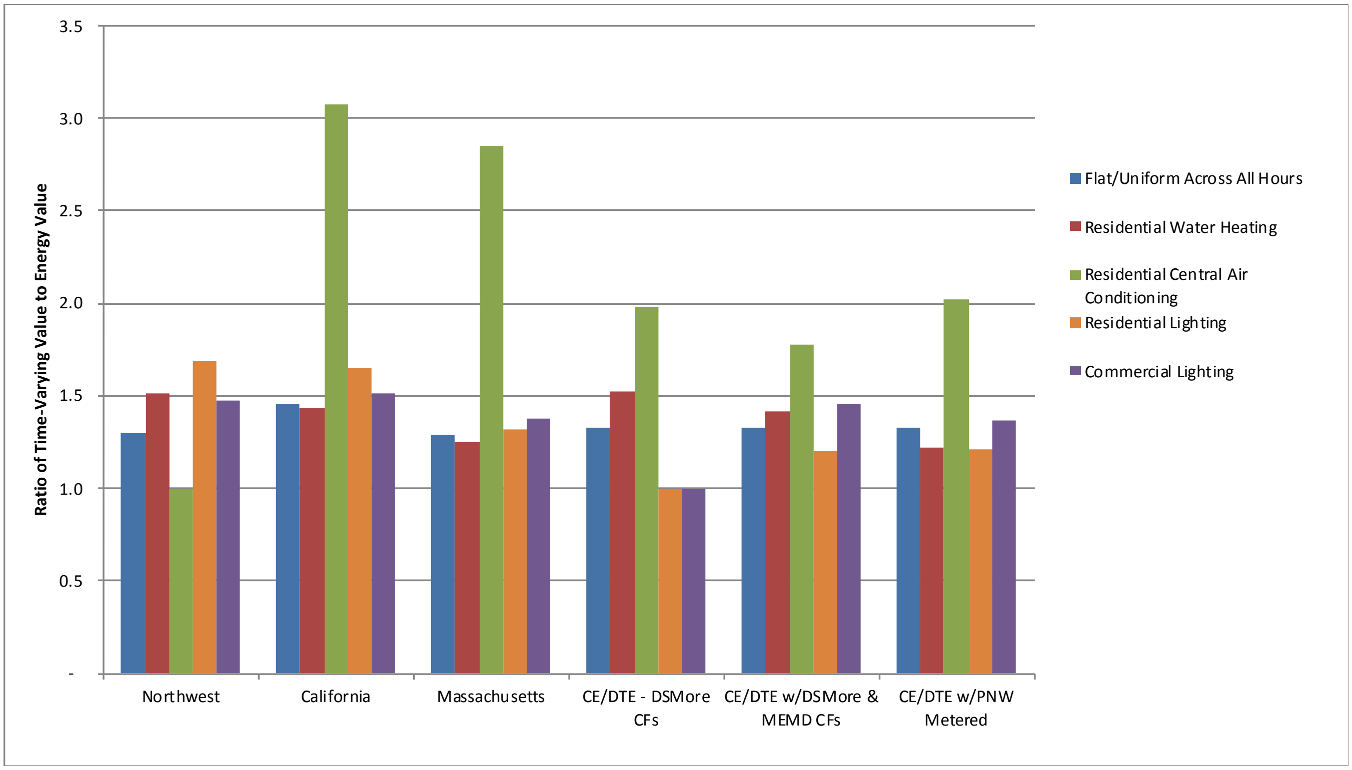
Figure 5 also displays data from two metering studies in the Pacific Northwest and illustrates how end-use load shapes may change over time. The ELCAP data is from the late 1980s, and the RBSA data is from 2011. End-use load shapes and energy savings shape data will become increasingly important as end-use load shapes change, and as a growing share of energy savings are from improved controls, which are explicitly intended to modify the duty-cycle or hours of operation of end-use consumption (e.g., occupancy controls for lighting).

7. RESULTS

Overall, the ratio of the **total** utility system value of energy savings to their **energy-related** value in Michigan aligns with other states with similar system load shapes. Figure 6 shows the ratio of the **total** time-varying value of electric efficiency measures (avoided cost of energy plus the avoided cost of capacity) to the **energy-related** value of savings for the five energy efficiency measures included in this study.[26] As Figure 6, Table 4 and Table 5 show, accounting for both the seasonal time-varying value of energy savings and its impact on the need to invest in additional capacity can significantly affect the total value of energy savings.

[26] To calculate the ratios in Figure 6, we divided the total time-varying value by the energy-related value subtotal. See Tables 5 and 6 for actual Michigan values.

Figure 6. Ratio of total time-varying value of energy savings to energy-related value by load shape and location[27]



When reviewing Figure 6, it is important to acknowledge several reasons that the value of a particular energy efficiency measure differs across electricity systems:

- **Load shape of the electricity system:** The difference in load shapes across electric systems, driven by differences in customer mix, building stock, and climate, can result in significant differences in the time-varying value for the same energy efficiency measure.
- **Inclusion or exclusion of types of avoided costs:** Significant differences in the value of energy savings can result from the type of benefits that are considered and estimated in avoided cost methods specified by states (Lazar and Colburn 2013).
- **Resource need:** Each electricity system is in a different position with respect to its need for additional generation, distribution, and transmission resources.
- **Resource availability:** Each electric system also has access to different resource options. For example, inadequate access to natural gas pipeline capacity may make gas-fired generation less competitive than coal-fired generation in certain areas. Similarly, wind resources across the Great Plains will likely be a more cost-competitive option for meeting RPS requirements than in areas where wind regimes are less favorable. As a result, each system has a unique set of avoided costs (and risk) to use in determining the value (i.e., cost-effectiveness) of energy efficiency.

Table 4 shows the time-varying value of savings for the exit sign, residential water heating and residential air-conditioning efficiency measures in Michigan using DSMore end-use load shapes, with the MEMD coincidence

[27] In Georgia, where publicly available data does not include avoided transmission and distribution system values, the time-varying value of efficiency appears much lower than if the proprietary values were included. This is true for all measures displayed.

factors and end-use load shapes from Pacific Northwest metered data and coincidence factors derived through comparison of Pacific Northwest end-use load shapes with system load shapes for Consumers Energy and DTE Energy. Table 5 shows the time-varying value of savings for the exit sign, and residential and commercial lighting measures in Michigan using DSMore end-use load shapes, with the MEMD coincidence factors and end-use load shapes from Pacific Northwest metered data and coincidence factors derived through comparison of Pacific Northwest end-use load shapes with system load shapes for Consumers Energy and DTE Energy.

The first row of each table displays the energy-related levelized values of each measure. The value in row one is over an assumed useful life of 15 years, considering only the shape of the energy savings over the course of the year — the annual average value of a megawatt-hour of savings.[28] The second row displays the energy-related value subtotal.

Rows three through seven in each table display the capacity-related levelized values for each of the efficiency measures. Row three shows the levelized value of avoided generating capacity resulting from the reduction in system peak demand due to the measure. Row 4 provides the value of reducing the need for reserves and ancillary services. By reducing the need for additional generation capacity, efficiency savings also reduce the requirement to add reserves and other ancillary services for that capacity.[29] Rows five and six show the levelized value of deferring transmission and distribution[30] system expansion resulting from reducing the rate of growth in peak demands. Row seven is the capacity-related value subtotal. The exit sign values serve as a point of comparison for other measures in Michigan as the signs operate every hour of the year. Moreover, since exit signs have the same load shape regardless of climate or location they provide a point of comparison that is independent of climate and location.

Table 4. Time-varying value of an exit sign, residential hot water and air conditioning savings in Michigan using DSMore load shapes + MEMD coincidence factors and Pacific Northwest load shapes ($2016/MWh)*

	Resource Benefit	Exit Sign (MEMD and PNW)	Res. Air Conditioning (MEMD)	Res. Air Conditioning (PNW)	Res. Hot Water (MEMD)	Res. Hot Water (PNW)
1	Energy	$56	$108	$127	$65	$58
2	**Energy-Related Value Subtotal**	**$56**	**$108**	**$127**	**$65**	**$58**
3	Generation Capacity	$9	$39	$60	$13	$6
4	Reserves/Ancillary Services	$0	$2	$3	$1	$0
5	Transmission	$10	$44	$67	$14	$7
6	Distribution[31]	$0	$0	$0	$0	$0
7	**Capacity-Related Value Subtotal**	**$19**	**$84**	**$129**	**$27**	**$13**
8	**Total Value**	**$74**	**$192**	**$256**	**$92**	**$70**

***Values in table may not sum due to rounding.

[28] These levelized values are based on electricity savings at the generator (i.e., they include transmission and distribution system losses). They do not reflect the "source" energy (i.e., the British Thermal Units input) required to produce a kWh.
[29] For some utilities, the value of ancillary services is captured in the value of deferred generation.
[30] Throughout this analysis, the value of avoided transmission also includes the value of avoided distribution cost for the Michigan utilities.
[31] The value of deferred distribution investments is included with transmission savings.

RESIDENTIAL AIR-CONDITIONING RESULTS

A comparison of the data by source for the residential air-conditioning end-use load shapes in Table 4 reveals significant differences in the results. Based on both sets of input assumptions, residential air- conditioning savings have the greatest total value. However, the value of capacity savings derived by using the DSMore load shape for residential air conditioning is substantially lower than using the metered load shape for this end use ($84/MWh vs. $126/MWh). Moreover, the value of energy derived from using the DSMore shape is greater than the value of capacity for residential air conditioning ($108/MWh vs. $84/MWh. In contrast, the use of a metered load shape for this end use results in a value for capacity that is roughly equivalent to the value of energy savings ($129/MWh vs. $127/MWh). These differences result from the use in DSMore of the whole premise residential load shape as a proxy for residential air conditioning's load shape (See Figure 5). Use of this load shape assigns more of the energy savings to other times of the day than does the metered air conditioning load shape.

RESIDENTIAL WATER HEATING RESULTS

Similar to the residential air-conditioning end-use shape used in DSMore, the residential water heating end-use load shape is based on the whole-premise residential load shape rather than a water heating end-use load shape (see Figure 4). Therefore, the DSMore end-use load shape results in different values than metered data. In this case, the DSMore load shape assigns a greater proportion of water heating savings to high load hours. This results in an overstatement of both the energy value of water heating savings ($65/MWh vs. $58/MWh) and a value for capacity savings that is more than double the value of those derived from the Pacific Northwest metered water heating load shape data ($27/MWh vs. $13/MWh), as shown in Table 4.

Table 5. Time-varying value of residential and commercial lighting in Michigan using DSMore load shapes + MEMD coincidence factors and Pacific Northwest load shapes ($2016/MWh)*

	Resource Benefit	Re. Lighting (MEMD)	Res. Lighting (PNW)	Com. Lighting (MEMD)	Com. Lighting (PNW)
1	Energy	$75	$56	$61	$60
2	**Energy-Related Value Subtotal**	**$75**	**$56**	**$61**	**$60**
3	Generation Capacity	$7	$6	$13	$10
4	Reserves/Ancillary Services	<$1	<$1	$1	<$1
5	Transmission	$8	$6	$14	$12
6	Distribution[32]	$0	$0	$0	$0
7	**Capacity-Related Value Subtotal**	**$15**	**$12**	**$28**	**$22**
8	**Total Value**	**$90**	**$69**	**$89**	**$83**

***Values in table may not sum due to rounding.

RESIDENTIAL LIGHTING RESULTS

A comparison of the data for residential lighting in Table 5 reveals significant differences in the time-varying value of efficiency results. The DSMore end-use load shape for residential lighting overstates the value of energy as compared to the metered data from the Pacific Northwest by more than $20/MWh. The value of capacity savings derived from using the DSMore load shape for residential lighting is higher than using the metered end-

[32] The value of deferred distribution investments is included with transmission savings.

use load shape for this end use ($15/MWh vs. $12/MWh). The value of energy savings derived from using the DSMore shape is significantly higher than using the metered end-use load shape for residential lighting ($75/MWh vs. $56/MWh). These differences result from the use of a very narrow residential lighting operating schedule in DSMore (See Figure 3).

COMMERCIAL LIGHTING RESULTS

Table 5 shows that the commercial lighting energy-related value from both sources is very similar ($61/MWh vs. $60/MWh). The value of capacity savings derived from using the DSMore load shape for commercial lighting is higher than using the metered end-use load shape for this end use ($28/MWh vs. $22/MWh). The commercial lighting load shape in DSMore ramps up at 8 am and declines at 4 pm each day, which may not accurately capture the diversity in lighting schedules in commercial lighting applications.

COINCIDENCE FACTOR AND CAPACITY RESULTS

As discussed in the text box on page 6, a coincidence factor accounts for whether an end-use efficiency measure is reducing use at the same time as the electricity system peak demand. The Michigan utilities use the coincidence factor obtained from the MEMD (see Table 1) to calculate demand impacts.

Table 6 displays the coincidence factors from MEMD and those derived by comparing the hourly metered load shape data from the Pacific Northwest with the average hourly load shapes for Consumers Energy and DTE Energy systems. Table 6 also shows the maximum non-coincident demand and peak demand savings for each load shape in this analysis using the coincidence factors from MEMD and Pacific Northwest metered data.[33]

The coincidence factors drawn from MEMD differ from those derived from metered end-use data from the Pacific Northwest for three of the five end-uses considered in this study (residential lighting, residential air conditioning, and residential hot water), as shown in Table 6.[34] This does not necessarily mean that the MEMD coincidence factors are inaccurate. However, it may be worthwhile to explore the MEMD coincidence factors to verify that the savings anticipated to occur coincident with the system peak are occurring at the time expected. This likely will require end-use metering.

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[33] Non-coincident demand is the sum of the individual maximum demands, regardless of time of occurrence within a specified period. (Stern and Spencer 2017). Peak hour savings for each end use were calculated by multiplying the coincidence factors from the MEMD and the maximum hourly non-coincident demand from DSMore.
[34] The MEMD coincidence factor for commercial lighting, while not an exact match to metered data, is quite close to the ELCAP data.

Table 6. Capacity savings input assumptions used in the analysis

End Use (Source of data, if applicable)	Coincidence Factor	Maximum Non-Coincident Demand (MW)	Coincident Peak Load Reduction (MW/MWh)	Source
Residential				
Lighting	0.10	0.98	0.10	Michigan Energy Measures Database
Lighting (RBSA)[35]	0.25	0.31	0.08	Metered or Simulated Load Shapes
Water Heating	0.71	0.25	0.18	Michigan Energy Measures Database
Water Heating (RBSA)	0.21	0.40	0.08	Metered or Simulated Load Shapes
Central Air Conditioning (CAC)	0.72	0.75	0.54	Michigan Energy Measures Database
CAC – Lansing (Building America)[36]	0.49	7.28	3.59	Metered or Simulated Load Shapes
CAC – Detroit (Building America)	0.53	4.41	2.35	
CAC – (RBSA)	0.36	2.29	0.83	
CAC – (ELCAP)	0.48	2.91	1.40	
Commercial				
Exit Sign (Flat)	1.00	0.12	0.12	Michigan Energy Measures Database
Office Lighting	0.49	0.37	0.18	
Office Lighting – California Energy Commission (CPUC)[37]	0.76	0.29	0.22	Metered or Simulated Load Shapes
Office Lighting – (ELCAP)	0.52	0.28	0.14	

[35] In the late 1980s the Bonneville Power Administration metered approximately 500 single-family homes and 80 commercial buildings at the end-use level for a period of three years in its End Use and Consumer Assessment Project (ELCAP). More recently (2012), the Northwest Energy Efficiency Alliance metered approximately 100 single-family residences at the end-use level for a period of 18 months in its Residential Building Stock Assessment (RBSA) project. See Berkeley Lab's *Time-varying value of efficiency* report for a detailed description of these projects.
[36] Comparisons of daily commercial and residential end-use load shapes based on metered data by electric reliability area can be performed on the EPRI's End Use Load Shape Library website. Available at http://loadshape.epri.com/enduse.
[36] https://openei.org/datasets/files/961/pub/
[37] http://www.deeresources.com/

SUMMARY OF RESULTS

Overall, the ratio of the **total** utility system value of energy savings to their **energy-related** value in Michigan aligns with other states with similar system load shapes. As Figure 6, Table 4 and Table 5 show, accounting for both the seasonal time-varying value of energy savings and its impact on the need to invest in additional capacity can significantly affect the total value of energy savings.

- When investigating alternative data sources for the analysis, we also found that substitution of simulated end-use load shapes may not accurately represent the hourly distribution of energy use unless the data reflects diversity of occupant behavior.

- Utilities in Michigan are using whole home data to represent two of the five measures included in this study — residential hot water and air-conditioning. This may overstate the value of residential water heating savings (see Figure 4 and Table 4) and understate the value of air-conditioning savings (see Figure A-2). The whole home shape is not an accurate representation of the water heating or air-conditioning end uses for DSM or IRP planning purposes. The MEMD coincidence factors for these measures are high compared to metered data (see Table 6).

- The DSMore residential lighting end-use load shape has three hours of energy savings each evening, regardless of the day or season (see Figure 3). This result may overstate the value of these savings (see Table 5) and is not an accurate representation of the end use for DSM or IRP planning purposes. The coincidence factor used in the MEMD is low compared to metered data (see Table 6).

- The commercial lighting load shape in DSMore ramps up at 8 am and declines at 4 pm each day. This may not accurately capture the diversity in lighting schedules in commercial lighting applications.

- Exit sign values serve as a point of comparison for other measures in Michigan as the signs operate every hour of the year.

8. CONCLUSIONS

Quantifying the time-varying value of energy efficiency is necessary to properly account for all of its benefits and costs and to identify and implement efficiency resources that contribute to a low-cost, reliable electric system. Historically, most quantification of the benefits of efficiency have focused largely on the economic value of annual energy reduction. Due to the lack of statistically representative metered end-use load shape data in Michigan (i.e., the hourly or seasonal timing of electricity savings), the ability to confidently characterize the time-varying value of energy efficiency savings in the state, especially for weather-sensitive measures such as central air conditioning, is limited.

Still, electric utilities in Michigan can take advantage of opportunities to incorporate the time-varying value of efficiency into their planning. For example, end-use load research and hourly valuation of efficiency savings can be used for a variety of electricity planning functions, including load forecasting, demand-side management and evaluation, capacity planning, long-term resource planning, renewable energy integration, assessing potential grid modernization investments, establishing rates and pricing, and customer service (KEMA 2012). In addition, accurately calculating the time-varying value of efficiency may help energy efficiency program administrators prioritize existing offerings, set incentive or rebate levels that reflect the full value of efficiency, and design new programs.

Based on our analysis of Consumers Energy and DTE Energy’s data, we conclude that:

- Overall, the ratio of the total utility system value of energy savings to their energy-related value in Michigan aligns with other states with similar system load shapes.
- End-use load shape research that is specific to Michigan would enable more accurate analysis of the time-varying value of efficiency.
- Until such time that statistically representative, metered data on end-use load shapes in Michigan are available, data from regions with similar energy consumption characteristics should be considered for adoption (e.g., we used Pacific Northwest end-use load shapes in our analysis because they are based on metered data and are very similar to the end-use load shapes for some measures from the Electric Power Research Institute (EPRI) End Use Load Shape Library that are applicable to Michigan)
- Use of current DSMore load shapes to determine both energy and peak savings may overstate the value of residential water heating savings (see Figure 4 and Table 4) and understate the value of air-conditioning savings (see Figure A-1).
- Lack of statistically representative metered end-use load shape data for Michigan limits the ability to confidently characterize the time-varying value of energy efficiency savings, especially for weather-sensitive measures such as central air conditioning.
- Investigating alternative data sources for the analysis, we found that substitution of simulated end-use load shapes may not accurately represent the hourly distribution of energy use unless the data reflects diversity of occupant behavior (see Figure A-1).
- Investigation of all value streams for energy efficiency in Michigan will help avoid undervaluing this resource. For the purpose of this analysis, we assumed that there is no value for DRIPE or avoided fuel price risk, air emissions, and RPS compliance costs. Prior analysis by Berkeley Lab (Mims et al. 2017) found that in states where avoided cost includes a value for the risk mitigation benefits of energy efficiency, the total value of savings increased by 3-5 percent, depending on load shape. Including DRIPE also increased the value of savings, by about 5 percent. For those jurisdictions which include a value for reduced carbon dioxide emissions, the total value of energy savings increased significantly — by 6-13 percent in California, 13-28 percent in Massachusetts, and 32-52 percent in the Pacific Northwest.

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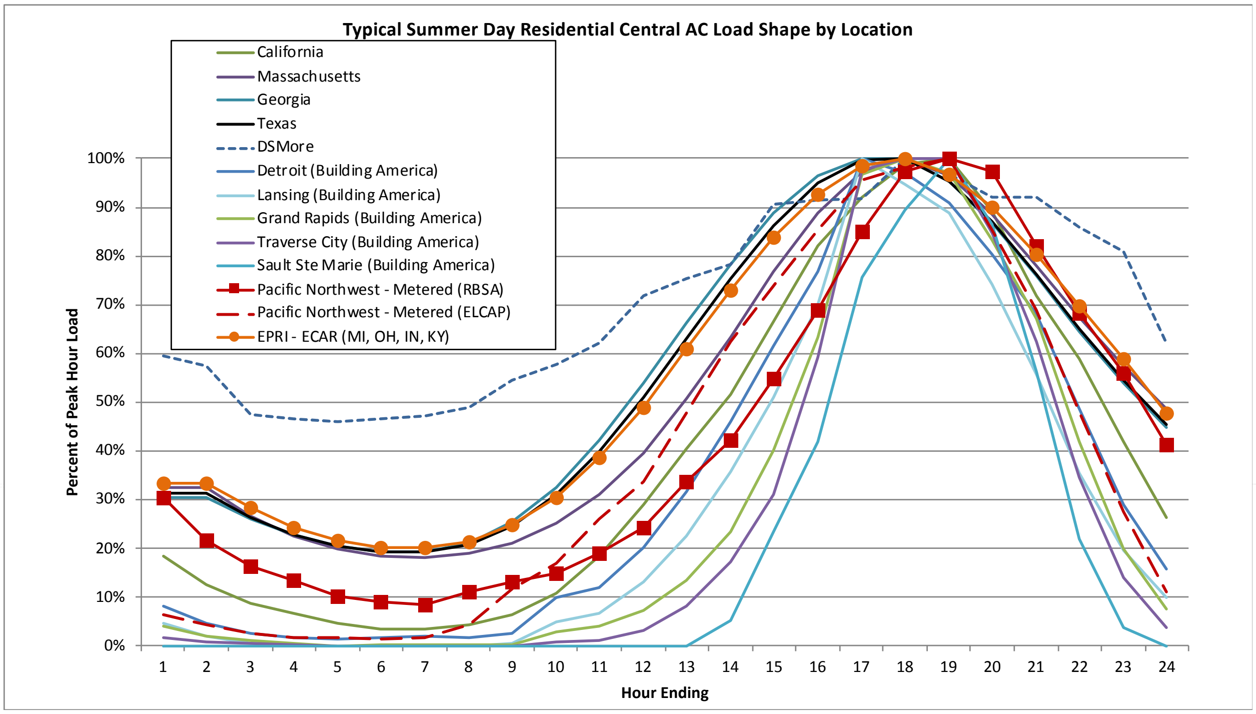
APPENDIX

When calculating the time-varying value of energy efficiency for residential air-conditioning, Berkeley Lab also investigated using simulated Building America data. Figure A-1 displays 13 residential air-conditioning load shapes for various regions. The DSMore load shape (dotted line) that is used to calculate the value of residential air-conditioning in Michigan is much higher in the morning and evening hours than the load shape from all other sources in Figure A-1.

Figure A-1. DSMore, metered Pacific Northwest, Building America and EPRI regional load shapes for residential central air-conditioning



In our investigation into the Building America data, we observed that the end-use load shape data that was derived from Building America[38] simulations, while reflecting weather sensitivity, may not accurately represent the hourly distribution of energy use unless the data can reflect diversity of occupant behavior. This potential error is displayed in Figure A-2, which shows estimates of the time-varying value of residential air conditioning savings based on three different load shape input assumptions. The highest value, over $500/MWh, is derived using the simulated end-use load shape from Building America. The lowest time-varying value is derived using the DSMore load shapes for residential air conditioning and coincidence factors drawn from the MEMD. It is just under $200/MWh. Use of the Pacific Northwest metered load shape for residential air conditioning to derive the time-varying value results in a value of approximately $260/MWh. The results shown in Figure A-2 illustrate the need to ensure that when simulation models are used to derive end-use load shapes, their inputs should reflect the diversity of occupant behavior so that peak demand savings are not overstated. In addition, the results shown in Figure A-2 indicate that the representation of residential air conditioning's load shape in DSMore underestimates of the value of energy savings for this load shape relative to the use of metered load shape by about one third.

[38] See https://openei.org/datasets/files/961/pub/

Figure A-2. Time-varying value of residential air conditioning end-use savings in Michigan derived from DSMore using MEMD coincidence factors and metered and simulated load shapes