# Chasing the Elusive Heat: Sherlock Holmes and the Startling Case of the CHP Protocol

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## ABSTRACT

Combined heat and power (CHP) systems provide host sites with both electricity and thermal energy. For decades, large-scale CHP systems have been widely used in the steel, chemical, paper, and petroleum-refining industries. More recently, smaller CHP systems are being deployed at university campuses, in the food and health industries and at commercial buildings. For utilities that offer CHP as part of an energy efficiency portfolio, it's important they understand the energy impacts of CHP systems. Not all installed CHP systems provide the expected levels of energy savings. Because CHP systems consume fuel, generate electricity and recover thermal energy; evaluating their energy impacts and pinpointing sources of problems can be complex. Determining the fate of the energy used in CHP systems can lead evaluators on an elusive hunt to "find the heat." Itron recently developed a CHP protocol for the National Renewable Energy Laboratory (NREL) Uniform Methods Project to help evaluate CHP systems.[1] The protocol provides a comprehensive and transparent method for estimating energy impacts from CHP systems located on the customer side of the meter. In addition to providing ways to estimate electricity impacts, the protocol includes algorithms and techniques for assessing CHP fuel impacts and calculating important performance metrics for installed CHP systems. CHP evaluations, like a good mystery story, contain traps to be avoided and secret doors to open. In this paper, we describe how the CHP protocol provides evaluators with an approach to navigate successfully through the mysteries associated with the evaluation of CHP impacts.

## Introduction: High Expectations for CHP

***"I'll tell it ye from the beginning" (Sherlock Holmes: A Study in Scarlet)***

Increasingly, utility customers are installing on-site generation systems to help meet their on-going electricity needs and obtain savings from reduced purchase of utility-generated electricity.[2] For example, a growing number of residential and small commercial customers are installing solar photovoltaic (PV) systems on their rooftops. PV systems not only help these customers be "environmentally green" but also help reduce their energy bills by offsetting the purchase of electricity. However, commercial customers that have both thermal energy and electricity needs are taking a serious look at CHP systems. CHP systems are uniquely designed to cost-effectively meet the dual-energy needs of these customers. Figure 1 demonstrates how CHP systems work in comparison to systems providing power and heat separately.

As shown in the upper, left-hand side of Figure 1, utilities supply electricity to customers using grid resources. These grid resources can be baseload power production facilities (such as combined cycle systems) or peaking systems (such as combustion turbines). As noted earlier, some customers are installing on-site electricity generators to help achieve savings through reduced purchase of electricity. These on-site electricity generation systems may be renewable energy-based systems such as solar PV or wind turbines which do not involve purchase of fuel. Other customers may install on-site generators such as internal combustion (IC) engines, fuel cells or microturbines that consume fuel. To reduce or eliminate purchasing electricity from the utility, these customers buy fuel to run their on-site generator to produce their own electricity. These same customers may also use on-site boilers to help meet their thermal energy needs. If so, they also buy boiler fuel (typically natural gas or oil) for use in the on-site boilers to produce needed on-site steam or hot water. The bottom, left-hand side of Figure 1 depicts the production of thermal

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[11] Simons, G and Barsun, S., Itron, "Chapter 23: Combined Heat and Power, The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures," November 2016

[2] WestMonroe Partners, "Preparing for Distributed Generation Growth: How Utilities Can Benefit from a Distributed Energy Resource Management System," 2017 cited from http://www.westmonroepartners.com/Insights/Newsletters/West-News-Energy-and-Utilities-March-2015/Preparing-for-Distributed-Generation-Growth

energy from on-site heating system. Together, the upper and bottom left-hand side of Figure 1 depict the separate power and heat (boiler) systems.

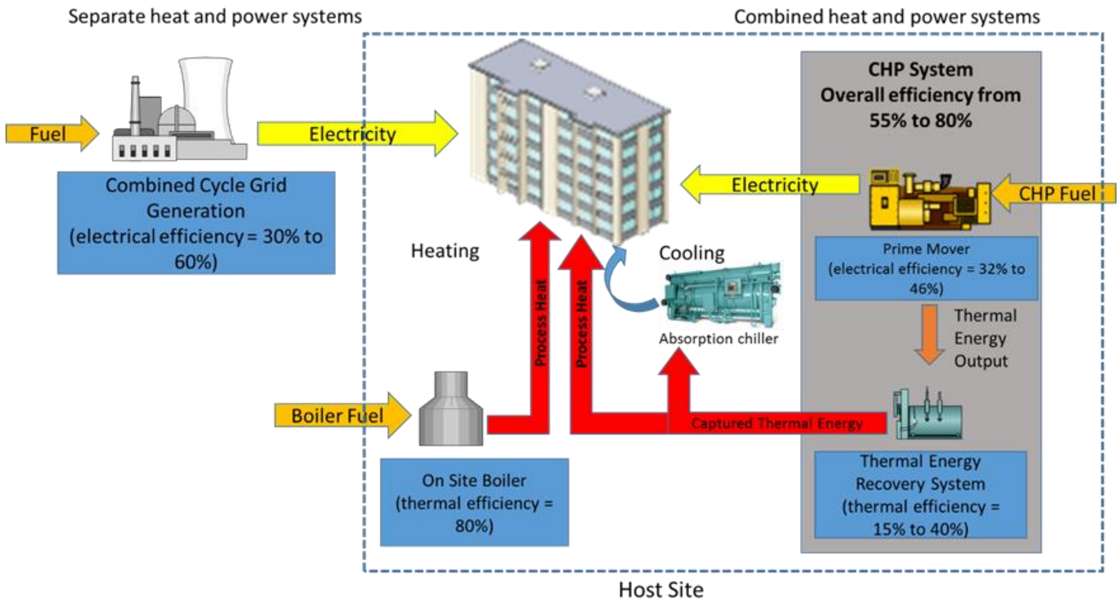


**Figure 1: CHP systems relative to separate power and heat systems (*Source*: Itron 2016)**

Under the separate power and heat systems approach, customers buy fuel for both the generator and boiler. CHP systems offer a distinct advantage to customers in that they can help satisfy both electricity and thermal energy needs while the customer may only have to buy fuel for the electricity generator. The generator (also known as the prime mover) in the CHP system consumes fuel to produces electricity. At the same time, the combustion process produces hot exhaust gases that contain energy in the form of heat. Heat recovery equipment located in the CHP system recovers the heat contained in the hot combustion gases and produces needed on-site steam or hot water. This means the customer obtains hot water or steam while significantly reducing or eliminating the need to purchase boiler fuel. Moreover, if the customer also has on-site cooling needs it may be possible to use recovered heat in an absorption chiller to meet on-site cooling demands.

A variety of prime movers can be used in CHP systems including internal combustion engines (IC engines), small gas turbines, steam turbines, microturbines and fuel cells. Appropriately designed and constructed CHP systems can be significantly more efficient than separate heat and power systems. CHP systems can also be extremely reliable, and under certain conditions can provide backup power for the customer while helping increase reliability for the utility.[3] All in all, CHP systems promise significant benefits to both customers and the utility.

## A Mystery Unfolds

***"I make nothing of it," I answered frankly. "It is a most mysterious business." (Sherlock Holmes: The Red-Headed League)***

Due to their promising benefits, utilities are seeing growth in small-scale CHP systems. Between January 2000 and the end of 2014, over 2,000 new and smaller-sized CHP systems (5 MW and smaller in capacity) representing over 2,200 MW of generating capacity were installed in the United States; equaling the same capacity of small-scale CHP that had been installed in the previous 80 years.[4] In addition, many utilities are including CHP systems as part of their energy efficiency portfolio or are providing incentives to help customers install CHP. Thirty-

[3] U.S. Department of Energy, "Quadrennial Technology Review 2015 Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing," 2015

[4] Data taken from Department of Energy, CHP database, https://doe.icfwebservices.com/chpdb/

one states including Massachusetts, New York, California, New Jersey and Illinois offer incentives to help develop and implement CHP systems.[5]

It is easy to understand the business case for CHP when looking at sites where installed CHP systems meet or exceed expectations of performance. In those instances, CHP systems provide energy savings both from avoided fuel and electricity purchases. However, like other measures, CHP systems do not always meet or exceed expectations. When CHP systems fail to meet expected performance, the business case for CHP is more difficult to understand. From an evaluator perspective, it is important to understand the underlying reasons why the CHP system failed to achieve expected performance. Comparing the electricity and heat recovery profiles of well performing CHP systems against the profiles of poorly performing CHP systems begins to provide insights into the underlying causes for poor performance. Figure 2 shows the electricity and heat recovery profiles for a well-performing CHP system while Figure 3 shows similar profiles for a poorly performing CHP system.

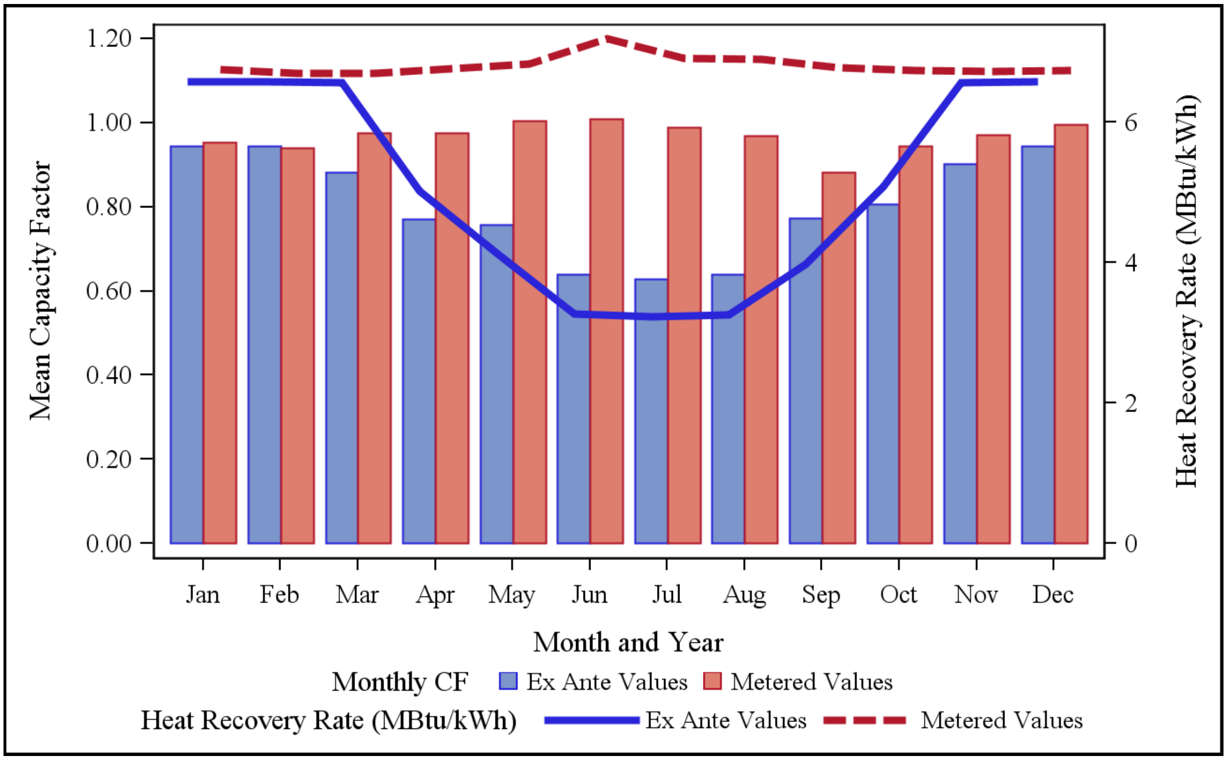


**Figure 2: Example of a well-performing CHP system (*Source*: KEMA/Itron 2013)**

The blue bars and lines represent the expected ("Ex Ante" values) monthly electricity capacity factors (left axis) and heat recovery rates (right axis) for the CHP system.[6] The red bars and lines represent the observed ("Metered") values. In this example, note that the expected (blue line) electricity capacity factor falls below the metered (blue bar) values, indicating that the CHP system is consistently generating more power than was expected. Similarly, the expected heat recovery rate (red bars) fall below the metered (red lines) values, indicating that the CHP system is recovering more heat than was expected. Consequently, this CHP system is considered a well-performing CHP system.

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[5] Data taken from Environmental Protection Agency "dCHPP (CHP Policies and Incentives Database)," https://www.epa.gov/chp/dchpp-chp-policies-and-incentives-database

[6] The capacity factor represents the amount of electricity actually delivered relative to the rated capacity of the generator. Heat recovery rate refers to the amount of heat delivered by the CHP system.

In contrast, the CHP system depicted in Figure 3 illustrates a poorly performing system. This CHP system was expected to act as a baseload electricity generating system producing the same amount of electricity month to month throughout the year; while recovering slightly different amounts of thermal energy each month. However, from July through August, the metered electrical capacity (blue line) values fell below the expected (blue bars) values. Similarly, the metered heat recovery rate (red line) values fell below the expected values from June through September. The CHP system was operating well below expectations during the summer months.

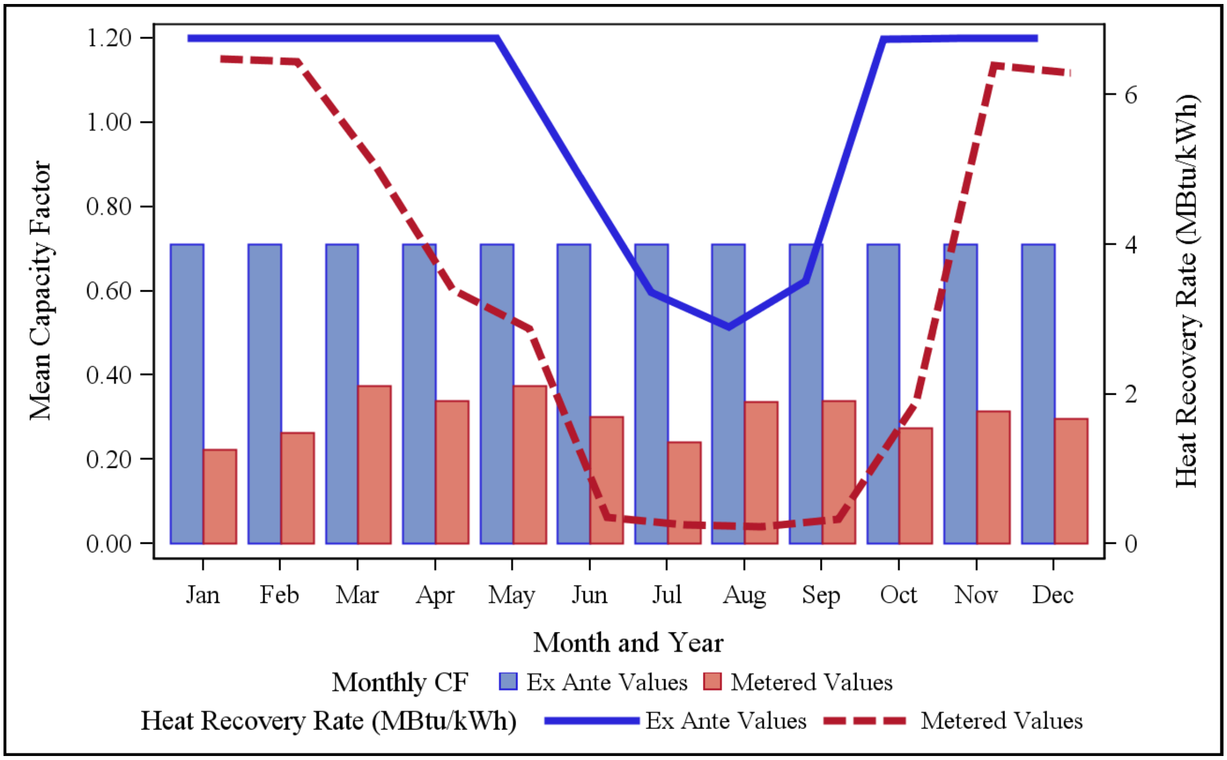


**Figure 3: Example of a poorly performing CHP system (*Source*: KEMA/Itron 2013)**

Conceptually, the behaviors of both the well and poorly performing CHP systems appear to make sense because of the direct relationship between electricity generated and thermal energy produced. That is, higher electrical generation rates should result in higher thermal energy rates and vice versa.

Things begin to get confusing when we see mixed performance results. Figure 4 shows such a situation. For this system, both the electrical and thermal energy values are reported on a capacity factor basis. That is, the actual electrical generation is normalized to the nominal rated power output of the CHP system. Similarly, the thermal output is normalized to the nominal rated thermal output of the thermal recovery system. Note that the thermal energy metering system went out in April; consequently, no thermal energy data is reported for April.

What we see poses a mystery. The observed electricity performance values (blue line) exceed the expected values (blue bars): that is, the power production component of the CHP system is performing better than expected. In contrast, the observed thermal recovery performance values (red line) fall below the expected values (the red bars). This means that although the CHP is producing power at levels above expectations, the thermal or heat recovery part of the CHP system is underperforming. This mixed performance runs contrary to the logic that higher electricity generation performance should lead to higher thermal energy performance. In addition, what has happened to the heat recovered in the heat recovery system? Heat cannot simply have disappeared! Resolving this mystery requires assembling the appropriate data for assessing CHP impacts and a systematic approach to evaluating CHP impacts.

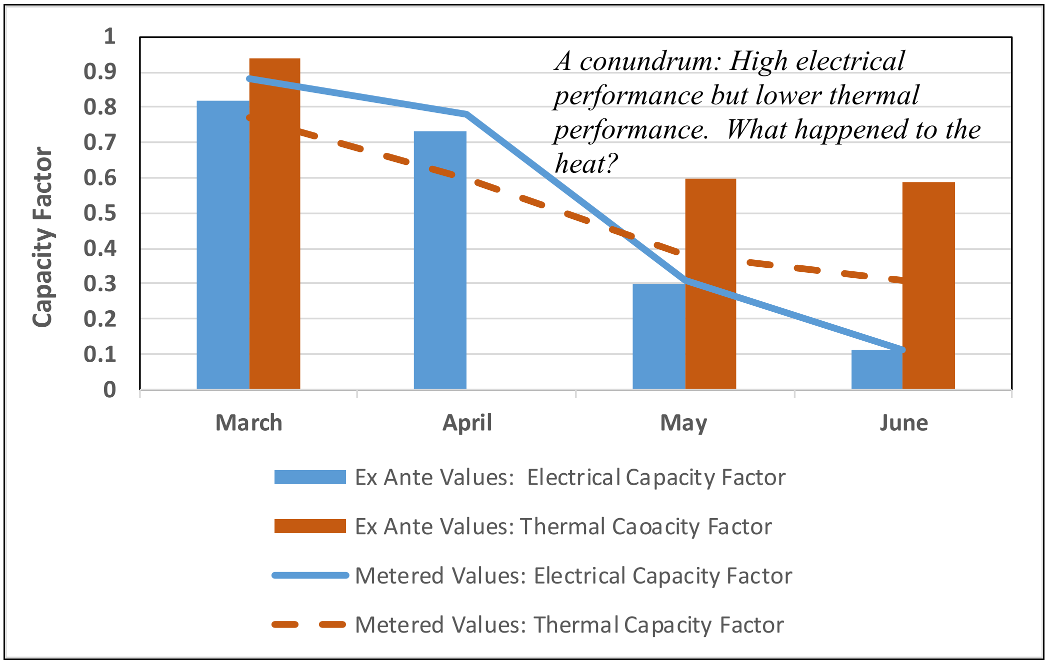


**Figure 4: Example of mixed CHP system performance (*Source*: KEMA/Itron 2013)**

## Methodology and Approach: The Sleuth's Tools

***"You know my method. It is founded upon the observation of trifles." (Sherlock Holmes: The Bascombe Valley Mystery)***

CHP systems are complex and evaluators unfamiliar with CHP systems may become frustrated with estimating energy impacts much less ferreting out the fate of the elusive heat. Breaking the complex situation into simpler pieces can help. We break the approach of evaluating CHP system impacts into three pieces: a) an overview of the impacts evaluation; b) a measurement and verification (M&V) plan to help guide the evaluation; and c) a process for implementing the plan elements.

### Overview of Assessing Impacts

***"Nothing clears up a case so much as stating it to another person." (Sherlock Holmes: Silver Blaze)***

Once Holmes explained his methods, his clients often felt his observations and conclusions were exceedingly straight forward. We hope the same is true of our explanation of how to approach evaluating CHP impacts. We start the evaluation of CHP systems impacts by using an energy balance approach. An energy balance simply means that the amount of energy entering a system is equal to the energy used by the system minus any energy leaving the system. CHP systems have three energy streams that must be evaluated: the electricity stream, the thermal energy stream and the fuel stream. Because CHP systems act to displace existing energy streams, we must also consider the baseline conditions; or what would happen in the absence of the CHP system. Figure 5 conceptually represents the different energy streams involved in a CHP system as well as a baseline condition of the host site prior to installing a CHP system.

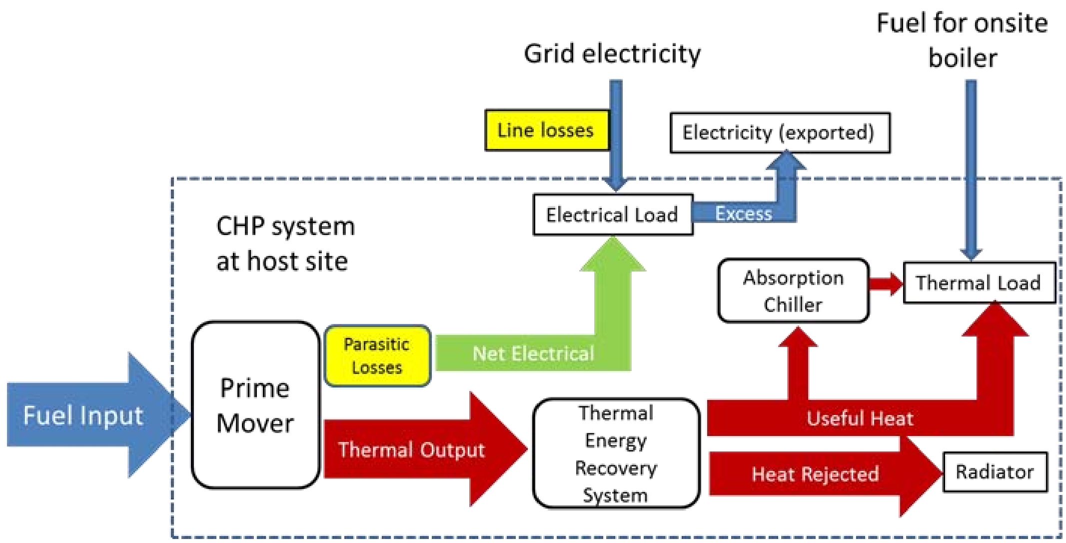


**Figure 5: CHP and baseline energy flows (*Source*: Itron 2016)**

**Electricity Stream and Impacts:** The bottom left hand of the figure shows the prime mover consuming fuel to produce gross electricity. Parasitic losses[7] reduce the amount of electricity available for actual use (i.e., net electricity). The net electricity serves on-site electrical loads that would otherwise be served by the grid, thereby reducing grid-generated electricity required by the customer. In certain instances, electricity generated by the CHP system may exceed the electrical load of the customer, and, if allowed, the electricity can be exported to the grid. Note that the baseline condition would be represented by the absence of the CHP system and the customer would be buying electricity from the grid.

Electricity impacts are determined based on an hourly level and then aggregated up to an annual level. We define net electricity impacts at any hour *t* as follows:

$$(Net\ Electricity\ Impacts)_t = [(Gross\ Electricity\ Generated)_t - (Parasitic\ Losses)_t) + (Offset\ Chiller\ Electricity\ Use)_t]$$

**Thermal Energy Stream:** As the prime mover consumes fuel, it generates thermal energy in the form of hot combustion gases exiting the prime mover. As shown in the bottom part of the figure, the CHP thermal energy (heat) recovery system captures some fraction of the thermal energy. The recovered thermal energy can then be used to serve on-site thermal loads. In some instances, the on-site thermal load may decrease suddenly, and the amount of recovered heat exceeds the on-site load. In those situations, the excess heat is rejected through a "dump radiator." In some instances, useful heat is supplied to an absorption chiller, which can offset electricity normally consumed by an on-site electrical chiller or reduce other electrically served cooling loads.

Thermal energy recovery systems of CHP systems are important because they can offset all or a significant portion of the fuel consumed by on-site boilers. Ultimately, the energy impacts of the thermal energy stream are embodied in the overall amount of fuel consumed by the CHP system relative to the boiler fuel baseline; known as the "fuel offset." The fuel offset depends on the useful heat recovery achieved by the CHP system. CHP system design (e.g., sizing) and the timing and magnitudes of the host site electrical and thermal loads play key roles in determining a CHP system's heat-recovery rate.

**Fuel Stream and Impacts:** There are two competing and opposite actions occurring with fuel consumption in CHP systems. The prime mover is consuming fuel while the CHP thermal recovery system is offsetting boiler fuel

[7] Parasitic losses are those electricity uses associated with operating the CHP system and can occur with a variety of the equipment associated with the CHP system (e.g., pumps and fans for moving fluids or gases).

consumption that would have occurred in the absence of the CHP system. We define the hourly fuel impacts at time *t* as follows:

$$(Fuel\ Impacts)_t\ =\ (Fuel\ Offset)_t -\ (Fuel\ Consumed\ by\ Prime\ Mover)_t$$

The overview defines the overall energy relationships between CHP system components and lays an important foundation for accurately assessing CHP energy impacts. However, in assessing CHP energy impacts it is also critical to understand what is meant by expected CHP performance and how it is measured; in knowing what data should be metered and understanding the mathematical means for using the data to evaluate CHP system performance These items are covered in the measurement and verification (M&V) plan.

**Measurement and Verification Plan**

***"Data! Data! Data!" he cried impatiently. "I can't make bricks without clay." (Sherlock Holmes: The Adventure of the Copper Beeches)***

CHP evaluation involves collecting data from a variety of sources, orchestrating these data in ways to identify key relationships and determining the CHP energy impacts. Information forms the heart of the evaluation process. Our proposed M&V plan has six key elements to help plan the approach and assemble the needed pieces of information:

- Identifying sources of data for determining expected performance;
- Determining the specific M&V method to be used under the International Performance Measurement and Verification Protocol (IPMVP);
- Identifying CHP performance data to be collected and methods for collecting the data;
- Handling multiple fuels;
- Establishing the sample design; and
- Considering interactive effects.

**Expected performance**: Two good sources of expected performance of CHP systems include on-site inspection reports and utility tracking data. CHP systems installed as part of an energy-efficiency program typically undergo site inspections prior to receiving rebates. Site inspections may be conducted by the evaluation team or by other contractors. Generally, CHP project developers or host site representatives provide pre-inspection data within a program application. On-site inspections are conducted to verify installation of the CHP system nameplate ratings versus tracking data, check gross and net power and/or thermal energy output at the time of the inspection, and collect or coordinate delivery of relevant hourly trend data collected from the date of "regular" or "normal" operation.

During sizing of CHP systems, vendors typically develop estimates of CHP performance, including electricity generation and thermal energy production. In addition, many program administrators require vendors to submit estimated performance, or they may develop their own estimates of CHP performance. Expected CHP performance is contained in "tracking data," which acts as an expected baseline upon which program administrators can project estimated impacts throughout the life of the system. When possible, these vendor or tracking data should be obtained to provide information on the expected CHP operation and performance.

*Trap to be avoided*: One important aspect of a site inspection is to establish when the CHP system "entered normal operation."[8] This is important because CHP system operation early on may be sporadic and show performance significantly below expected levels. Setting too early a date of normal operation may result in artificially lower estimates of energy savings. In some instances, utilities or evaluators have defined the date at which the system entered normal operation as the date when incentive checks have been first issued, which may be too early.

[8] There is considerable variability in perceptions within the CHP industry as to what constitutes "normal" operation and when a CHP system is considered to have operated sufficiently so it can be considered to have "entered normal operation."

In other instances, the date of normal operation has been as defined as the calendar date at which impact estimates for the program year are initiated. We recommend defining the date the system enters normal operations as when system commissioning has been completed and the system is operating much like it will under commercial operations (e.g., power and thermal output reach levels that are consistent with expected commercial operation for more than two months).This may require engineering judgement.

*Secret door*: Some utilities use algorithms for developing hourly expected electrical and thermal performance of CHP systems. Consider requesting the algorithms and key assumptions to help pin down the details of expected CHP performance.

**IPMVP method**: Under the IPMVP, there are four primary methods for evaluating energy impacts of installed measures.[9] We recommend an approach for verifying CHP savings that adheres to Option A—Retrofit Isolation: Key Parameter Measurement of the IPMVP. We recommend Option A because energy savings are determined by field measurement of key performance parameter(s) rather than all parameters being field-measured under Option B. Using Option A means installing less sub-metering equipment; therefore, represents a lower cost of evaluation. In addition, under Option A, estimates can be based on historical data, manufacturer's specifications, or engineering judgment.

**CHP Performance Data**: To assess energy impacts, data must be collected on CHP performance, including the amount of fuel consumed by the CHP system, electricity generated, and useful thermal energy supplied to the host site. Metered data to be collected include net electricity generated (kWh), net real power delivered (kW), and flow rates and associated inlet and outlet temperatures needed to determine useful thermal energy supplied to the host site.

Metered data represents conditions post-installation of the CHP system. It is important to use metered data only after the CHP system has completed commissioning and shakedown.[10] The amount of time for commissioning takes varies, but measurements can usually start once the CHP system operation approaches "normal" operation.

*Trap to be avoided:* There is usually no or limited metered data on hourly boiler fuel consumption. In these situations, interpolate monthly fuel consumption down to an hourly basis. This can be done by assuming a flat hourly profile or by using the hourly profile of the CHP generator. If metered prime mover fuel consumption is not available, it may often be estimated based on prime mover specification sheets and/or data from similar systems.

*Secret door*: Choose the measurement period (the length of the expected baseline and reporting periods) to capture a full year. A full year of operation is important in capturing the seasonal impacts of both the CHP system performance and facility operation. If a full year is not available, we recommend capturing at least six months of operational (post-installation) data, with at least one month in summer and one month in winter.

**Multiple Fuels**: Some projects may consume one fuel in the CHP measure to offset a different heating or cooling fuel. For example, the type of fuel consumed by the prime mover (e.g., natural gas) may be different than the type of fuel consumed by the existing boiler (e.g., oil). Care should be taken to capture all the impacts of the CHP measure on different fuel sources. The CHP protocol uses an energy balance approach. As such, using the heat content of the various fuels enables the energy impacts to be correctly captured.

*Trap to be avoided:* Increasingly, CHP systems are being installed in locations such as wastewater treatment plants, landfills, and dairies.[11] In these instances, CHP systems provide benefits by capturing and using the on-site biogas that would have otherwise been vented to the atmosphere or flared. In some of these locations, the host site may use on-site biogas in a boiler to meet on-site thermal needs but not to generate power. It is important to recognize the installation of a CHP system does not increase fuel consumption for these on-site biogas applications.

*Secret door*: For systems that use a mix of fuel and on-site biogas, use an estimated or measured ratio of the amount of on-site biogas fuel consumed to total fuel consumed on an energy basis to calculate the fuel impacts.

**Sample Design**: At times, evaluators must assess overall impacts to an energy-efficiency program that has multiple CHP systems. If the number of CHP systems is large, it may be cost prohibitive to collect metered data for all

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[9] Energy Valuation Organization, "International Performance Measurement and Verification Protocol," January 2010

[10] Shakedown refers to deliberately taking the system through different levels of operation to ensure each of the subsystems are and the system overall is operating within the design specifications.

[11] For example, see "2013 SGIP Impact Evaluation," Submitted to: PG&E and the SGIP Working Group, April 2015.

the installed systems. In that event, metered data may be collected from a sample of the operating CHP systems and extrapolated to the overall population.

Sample size depends on budgetary considerations. We recommend a census approach at the onset of an energy-efficiency program when CHP systems are beginning to be installed. As the program expands, sampling is recommended when installations of small and same-type systems exceed a population of 20 systems. For larger installations (e.g., 1 MW or larger), energy impacts are significant enough to warrant measurements of all the larger sites. In general, sample designs should be set to achieve 90% confidence with 10% precision, depending on budgetary constraints. Ideally, stratify the sampling of CHP systems by technology and/or the magnitude of claimed project savings. Stratify the sample by relevant metrics (e.g., technology type) to ensure you can confidently extrapolate sample findings to the remaining project population.[12]

*Trap to be avoided*: Not all received raw metered data are accurate. They may contain errors due to calibration issues, problems with meter operation, or other unforeseen non-system issues.

*Secret door*: All collected data should undergo validation. For example, collected data should be checked to ensure that date/time stamps match actual operation. Similarly, data validation techniques should be used to check and flag suspect data. For example, received electricity generation data that show values significantly higher than the rated generation capacity of the system should be flagged as suspect. Similarly, data that show zero delivered energy but high values for useful heat recovery should be flagged as suspect.

**Interactive Effects**: Some CHP projects may be installed with other efficiency measures that interact with the CHP measure. For example, a site that installed both a more efficient boiler measure and a CHP system would see no benefits from the new boiler when heating loads were met from the CHP system. In addition, the thermal savings from the CHP system would be reduced somewhat because the boiler efficiency would be higher. Similarly, a site that installed both a CHP system with an absorption chiller and a more efficient electric chiller would get no benefits from the electric chiller when cooling loads are met with the absorption chiller.

**Implementing the Plan**

***"Come, Watson, come!" he cried. "The game is afoot. Not a word! Into your clothes and come!" (Sherlock Holmes: The Adventure of the The Abbey Grange)***

The M&V plan provides evaluators with a way to design the approach and assemble the needed pieces of information. Armed with the necessary data, evaluators are ready to jump into the actual evaluation process.

One of the first steps involves determining the level of rigor needed in the results. Differing levels of rigor can be applied in estimating impacts of CHP projects. Some CHP evaluations require not only estimates of energy and fuel impacts but also that these estimates are provided on an hourly basis. This is a high level of rigor. This type of approach may be required when the evaluation needs to account for the impact of the CHP systems on peak demand, or if there is a need to determine the degree to which CHP electricity is coincident with useful thermal energy recovery.

Under a moderate rigor approach, only electricity impacts are evaluated on an hourly basis, whereas fuel impacts are evaluated on an annual basis. This situation can occur when the evaluation requires an assessment of the impact of CHP on electricity peak demand but there is no requirement to assess the coincidence of CHP electricity with useful thermal energy recovery.

A low rigor approach is one where the evaluation is focused only on annual impacts. This situation may typically be used for very small CHP systems or when CHP systems make up a small portion of an overall energy-efficiency program.

Once the level of rigor is decided, evaluators can begin assembling equations for estimating impacts. Our recommended approach specifies impact equations to use for each of level of rigor as appropriate. We also specify other detailed steps to calculating CHP performance metrics such as overall system efficiency and useful heat

[12] We recommend that evaluators consult the Uniform Methods Project: Chapter 11, "Sample Design Cross-Cutting Protocol," for general sampling procedures if the CHP system population is sufficiently large or if the evaluation budget is constrained.

recovery rate (UHRR). The UHRRR and the efficiency can be very helpful in resolving mysteries associated with mixed CHP performance results.

**Electricity impacts**: Estimating the electricity impact requires knowing the electrical efficiency of the CHP system.[13] Electrical efficiency, defined as a measure of how much of the energy in the fuel input is converted to net electricity, is also a key parameter for evaluating CHP performance. This efficiency is largely driven by the type and model of CHP prime mover.

Mathematically, the electrical efficiency is defined as follows[14]:

$$Electrical\ Efficiency_{HHV\ Basis} = \frac{(Net\ Electricity\ Generated_{kWh})}{(Fuel\ Input_{MBtu/hr}) \times \frac{1\ kWh}{3.412\ MBtu}}$$

Note that depending on rigor, the fuel input can be based on hourly values or annual values. Regardless of the rigor, evaluators should use the same time basis in the equations (e.g., hourly or annual).

**Fuel impacts**: Estimating fuel impacts require knowing the relationship between the prime mover and the thermal energy recovery system.

Hourly fuel impacts are based on the fuel consumed by the prime mover and the fuel offset. The fuel offset in turn depends on the amount of useful heat recovery achieved by the CHP system. UHRR is one measure of the effectiveness with which thermal energy is recovered from the prime mover and used to meet on-site thermal needs, either on-site heating loads or on-site cooling loads. Mathematically, the UHRR is defined as follows:

$$Useful\ Heat\ Recovery\ Rate\ (UHRR) = \frac{Useful\ Heat\ Recovered}{Net\ Electricity\ Generated}$$

Note that the useful heat recovered refers to heat that is recovered from the CHP system, delivered ***and*** used the customer. It includes any heat recovered for absorption chiller use and used on-site.

Electricity generation and recovered thermal energy (recovered heat) are combined to form an overall efficiency to quantify how much of the energy input is used. If a CHP system generates substantial quantities of electricity when facility thermal loads are low, large quantities of heat will be rejected to the atmosphere, which will reduce the overall efficiency of the CHP system. Overall efficiency is defined as follows:

$$Overall\ Efficiency = \frac{Net\ Electricity\ Generation + Useful\ Heat\ Recovered \times \frac{1\ kWh}{3.412\ MBtu}}{Fuel\ Input \times \frac{1\ kWh}{3.412\ MBtu}}$$

**A Mystery Resolved!**

Armed with methods and equations for investigating how energy is used and recovered by CHP system, we are now in a good position to understand and resolve the mystery surrounding the mixed performance CHP system.

Based on our new knowledge, what can we determine about the mixed performance seen in Figure 6 ? We know that the amount of heat generated by the prime mover is proportional to the generated electricity. Consequently, high electricity generation should coincide with high rates of generated thermal energy. In turn, thermal energy recovery systems are usually very efficient. Consequently, if the useful heat recovery rate (UHRRR) is lower than the expected values, it is most probably due to one of two reasons: 1) the customer thermal energy load

[13] It is typical to calculate electricity impacts first and then fuel impacts because it is usually easier to identify anomalies in electricity output. The electricity impacts can then be used to confirm thermal energy and fuel impacts; however, it is possible to calculate fuel impacts first and then electricity impacts.

[14] HHV refers to higher heating value. HHV is used to account for the water vapor that is produced in the combustion process and the energy associated with the heated vapor can be retrieved through condensing the water vapor.

is much lower than the expected levels; or 2) the amount of thermal heat being delivered to the customer is lower than what is expected.

We can determine if the customer thermal load is lower than the expected values by investigating the tracking data and the information submitted by the project developer. In some instances, the developer may have assumed that almost all the thermal energy entering the thermal energy recovery system was recovered and delivered to the customer. This creates unreasonably high expected values for the useful heat recovery rates.

The other possibility is that the customer thermal energy loads fluctuate and are lower than the design levels of the CHP thermal energy recovery system. Because the recovered heat exceeds the customer thermal energy load, the heat is dumped to the atmosphere by the dump radiator. In most instances, this can be confirmed through discussions with the CHP system operator. In this specific example, the customer thermal loads were lower than expected in May and June. Consequently, the heat recovered by the CHP system could not be used. The excess thermal energy was diverted to a "dump radiator"[15] wherein the thermal energy was dissipated to the environment.

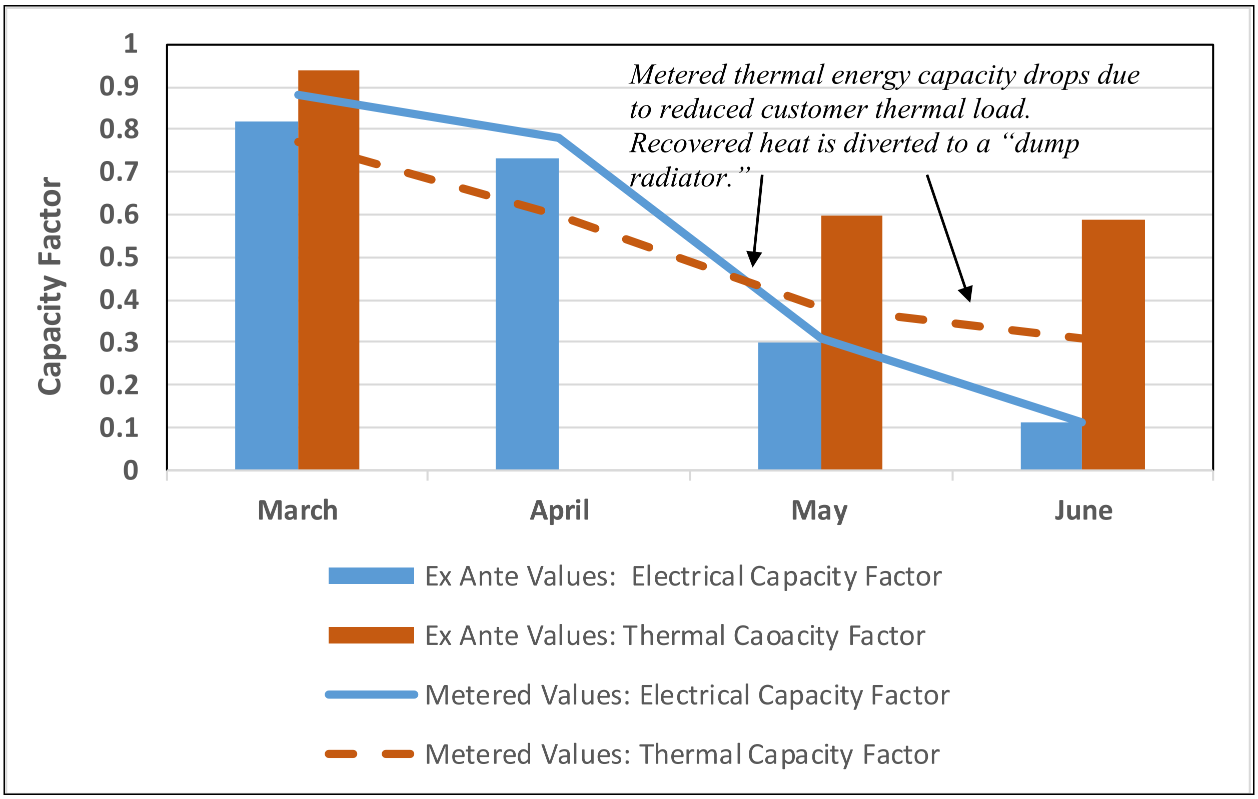


**Figure 6: Dissection of thermal energy performance of CHP system (*Source*: KEMA/Itron 2013)**

## Conclusions

***"It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts." (Sherlock Holmes: A Scandal in Bohemia)***

Our example of the CHP system showing mixed performance illustrates the danger of making assumptions about CHP performance without looking at the underlying facts. Based only on the thermal energy results, we may

[15] "Dump radiators" are used in CHP systems to allow the CHP system to operate when there are insufficient thermal loads at the site. We found dump radiators to be a common component of CHP systems. For example, see "Massachusetts Combined Heat and Power Program Impact Evaluation: 2011-2012," Massachusetts Energy Efficiency Program Administrators Massachusetts Energy Efficiency Advisory Council, November, 2013. In that study, over half the investigated CHP systems had dump radiators.

have incorrectly concluded that the CHP system was operating poorly. In fact, the CHP system was operating as designed; the observed lowered thermal energy levels were due to lower thermal demand at the site. Because utilities and customers make decisions based on reported evaluation results, it is essential that the results are based on a solid set of facts.

CHP systems promise significant benefits to both customers and utilities. However, CHP system impacts can be difficult to evaluate due to inter-related energy streams and assumptions made about CHP system performance. We have developed an approach for estimating CHP system impacts that breaks the evaluation into manageable steps. In addition, the evaluation protocol contains algorithms for calculating different energy impacts and built-in methods for checking the results that are developed. Key conclusions of the protocol include the following:

- CHP impact evaluations require metered performance data as well as tracking data
- In approaching the evaluation, it is important to recognize the degree of rigor needed in the results, which determines the time interval of the data to be used in the analysis
- Assumptions made about the CHP system performance, and the customer electricity and thermal energy loads are critical in accurately assessing the expected (ex ante) performance levels of the CHP system and
- Use of built-in checks and balances, such as comparing observed thermal energy recovery levels against thermal energy levels expected based on the electricity generated by the system and CHP efficiencies are important ways to validate CHP system impacts.

## References

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