Measurement and Verification Process for Heat Pump Water Heater Retrofitting

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Summary of the poster

In recent years, traditional electric water heaters are largely replaced with energy efficient heat pump water heaters. The savings impact from the retrofits needs to be measured and verified by an individual third party. Measurement and verification (M&V) experts play this role to provide an impartial, credible, transparent and replicable process to assess the energy savings for energy efficiency activities.

This poster introduces the general M&V process and a case study of quantifying the energy savings of an industrial heat pump retrofit project is provided for illustrative purpose of the proposed M&V process. The definition of M&V and how M&V works are introduced at the beginning as an overview of the general M&V process. Afterwards, the basic M&V project stages, namely, scoping study stage, M&V plan stage, baseline construction stage, post-implementation stage, performance assessment stage and performance tracking stage are given in a graphic style. At each stage, an M&V report with standard requirements will be delivered. Among all the M&V stages, M&V plan plays a key role in the whole M&V process and gives the complete procedure that needs to be followed for the evaluation of an M&V project. In the M&V plan, selection of M&V options, boundaries for the savings, the metering plan, baseline characterisation and the baseline adjustments methodology are the key issues for the savings determination and all this concepts are briefly reviewed in the poster. The general M&V process can be adopted to assess the power savings and the corresponding energy savings for all the energy savings projects.

The M&V for a heat pump water heaters retrofitting project is given as a case study of the general M&V process. The energy efficiency technologies related to the heat pumps and the coefficients of performance (COP) for heat pumps are introduced firstly as the background information for this project. The scoping study is performed for this project such that the existing water heating system auditing and the specifications of the proposed heat pump technologies are learned. Based on the results of the scoping study, detailed M&V plan including the M&V boundaries, M&V options, metering plan, baseline establishment and baseline adjustments methodologies are determined. According to the metering plan and the baseline methodologies, the baseline and the actual load profiles at the post-implementation stage are generated. On the availability of the load profiles, the performance of this project can be assessed in terms of weekday evening peak (18:00-20:00) average demand reduction and the average Time-of-Use power reduction. The assessed savings will be tracked quarterly in order to guarantee the sustainability of the performance of this project.

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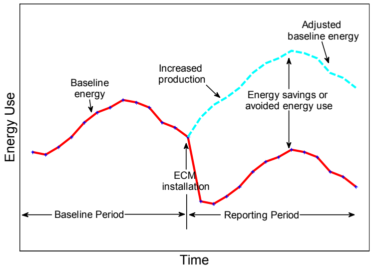
1. Introduction

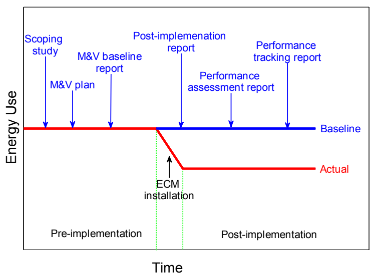
This poster introduces the general Measurement and Verification (M&V) process and a case study of quantifying the energy savings of an industrial heat pump retrofit project is provided for illustrative purpose of the proposed M&V process. M&V is the process used to evaluate performance of an energy savings project to support a guarantee of performance from an Energy Services Company (ESCO). M&V activities are guided by the International Performance Measurement and Verification Protocol (IPMVP) in many countries. M&V experts play the role to provide an impartial, credible, transparent and replicable process to assess the energy savings for the energy efficiency activities.

Figure 1. What is M&V



2. M&V projects stages

Figure 2. Basic M&V project stages



3. M&V options and metering plan

IPMVP M&V Options:

Option A: Retrofit isolation – key parameter measurement

Option B: Retrofit isolation – all parameters measurement

Option C: Whole facility – continuous measurement

Option D: Calibrated simulation – engineering modeling

One of these 4 options is selected to determined the metering plan for the identification of the project baseline and the calculation of the project savings. The boundary of the energy efficient interventions must be drew and must clearly state that the energy savings will be determined to include or exclude the interactive system effects.

Data requirements, variables, measurement points, equipment, metering intervals and duration must be included in the metering plan. Metering activities can be performed at either or both the pre- and post-implementation stage.

4. Baseline and baseline adjustment

Baseline energy use must be established and agreed to prior to the project implementation. Conditions of existing systems before the retrofitting will be used for the baseline. Existing conditions can be measured, **but only before the project begins!** The period of the measurement is usually set long enough to capture operational cycles. A 24-hour power consumption load profile is preferable to represent the baseline.

In case baseline is not measurable, energy system models, namely physical models, data models and stochastic modes can be built to recover the baselines at post-implementation stage.

Baseline must be adjusted at post-implementation period since conditions are different from those at the baseline period. Generally, baseline adjustments involve routine adjustments and non-routine adjustments. Factors normally apply for baseline adjustments are listed in the following:

Factors for routine adjustments: weather, occupancy, operating schedules, temperature settings, production level, etc.

Factors for non-routine adjustments: new equipment, changes of facility size, etc.

5. Savings calculation

Energy savings are the reduction in electric energy consumption as a result of increased efficiency, beyond what would have occurred without the project.

Energy savings = (Pre-implementation energy use) – (Post-implementation energy use)± Adjustments

Note that there is always a trade-off between the desired accuracy level of the savings and the M&V cost.

6. Heat pumps and COP

A heat pump offers you a way to use electricity to heat water efficiently. Coefficient of performance (COP) of the air source heat pumps is illustrated in the following and the COP values may be influenced by a number of factors but for the most part they are influenced by the change of ambient conditions. As shown in Figure 3, the ambient temperatures decrease the COP will decrease and as the ambient temperature rises so does the COP.

$$\text{COP}=\frac{\textbf{Heating/Coolingcapacity}}{\textbf{Electric input}}$$

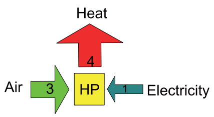
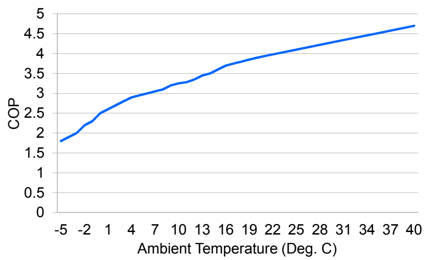


Figure 3. COP V.S. ambient temperature



7. Scoping study of the heat pump water heater retrofitting project

21 air sourced heat pumps are installed to replace the electric water heaters for a National Steel Mill Company with 5 divisions at 5 different cities in South Africa. Details of the involved water heaters and the specifications of the proposed heat pump technologies are given in Table 1 and Table 2.

Table 1. Distribution and power rating of the involved the water heaters

Site names	Number of existing water heaters	Power rating of each water heater (kW)
A	2	36
B	2	72
C	3	36
D	8	12
E	6	6

Table 2. Specifications of the proposed heat pump technologies

Site names	Heat pump model	Number of Heat pump	Power rating of each heat pump (kW)
A	M1	2	18.4
B	M2	2	23
C	M3	3	11.4
D	M4	8	4.8
E	M5	6	1.7

8. M&V plan for the heat pump retrofitting project

M&V boundaries: The savings will be determined to exclude interactive systems. Only the savings due to the retrofits of the traditional pure-resistance water heating boilers by the proposed heat pumps are evaluated.

M&V options: Option 'A' is selected for this M&V process since only power and ambient temperature of the selected heat pumps are measured.

Metering plan: Before the project begins, one water heating boiler from each site is selected and measured. Half-hourly active power data are recorded for one month. These data will be used for the baseline development. After the installation of heat pumps, the installed power meters take records of the energy consumption for the sampled heat pumps. The metered data will be adopted to assess the performance of this project. The relative COP values at different ambient temperature (see Figure 3) for each heat pump model are tested and provided by the heat pump suppliers. The ambient temperature is obtained from the Weather Service Company.

Baseline: The baseline is established for all the involved water heating systems. The average 24-hour load profile obtained from the metering data at the pre-implementation stage is the project baseline, denoted by $P(j, r)$, where $j=1,2,3,\ldots48$, denotes the time (48 half-hours), $r=1,2,\ldots,12$, means the month.

Baseline adjustments: At post-implementation stage, for Site A in the r-th month, the metered load profile is $Q_A(j, r)$, half-hourly ambient temperature $T(j, r)$, COP value can be denoted by $COP_A(j, r)$. Then the adjusted baseline for Site A is:

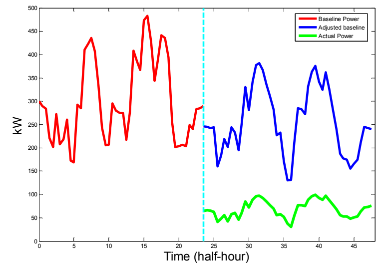
$$D_A(j, r)=2\times Q_A(j, r)\times COP_A(j, r).$$

The baseline adjustment for other sites can be obtained similarly. And the overall adjusted baseline $D(j, r)$ is the aggregation of the adjusted baselines form each site.

9. Load profiles for the heat pump retrofitting project

According to the M&V plan, when the metering data are available, the baseline, adjusted baseline and the actual power consumption load profiles can be obtained. As shown in Figure 4, the load profiles exhibit silent two peak demands. The saving is the difference between the adjusted baseline and the actual power consumption. COP values of the heat pumps will change as the weather conditions vary in different months. Therefore, **the generated load profiles should be given with critical time stamps**. For this project, the baseline load profile is calculated from the metering data in October 2011 before the installations of the heat pumps. The adjusted baseline and actual power consumption load profiles are obtained from the metering data in March 2012 in Figure 4.

Figure 4. Baseline and actual load profiles



10. Performance assessment

The installation for all the heat pumps are completed in February 2012 when the certificate of completion of this project was issued. The performance of this project will be assessed 3 times in 3 subsequent months after the implementation. Afterwards, the performance tracking will be done quarterly to check the sustainability of the savings of this project. The performance summary in March 2012 is provided in Table 3 and the performance in terms of Time-of-Use Tariff is given in Table 4.

Table 3. Performance summary in March 2012

Description	DSM target	Reporting period	YTD	ITD
Weekday evening peak average demand impact (kW)	215.0	200.3	18.2	200.3
Energy consumption impact (MWh)	156.9	139.7	139.7	139.7

Table 4. Average Time-of-Use power reduction

	Weekday						
	Morning Off-peak	Morning Standard	Morning Peak	Midday Standard	Evening Peak	Evening Standard	Off-peak
Baseline	229.1	310.7	342.4	272.9	221.5	167.3	234.6
Actual	57.5	80.3	86.1	72.6	63.4	51.2	71.0
Impact	171.6	230.4	256.3	200.3	158.1	116.1	163.6

	Saturday					**Sunday**
	Morning Off-peak	Morning Standard	Midday Off-peak	Evening Standard	Evening Off-peak	Off-peak
Baseline	240.8	281.4	300.6	221.5	220.4	255.9
Actual	60.7	71.8	80.0	63.4	65.4	68.2
Impact	180.0	209.6	220.5	158.1	155.0	187.8

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