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Expert Meeting Report: Exploring the Disconnect Between Rated and Field Performance of Water Heating Systems

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Alliance for Residential Building Innovation (ARBI)

May 2013

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Expert Meeting Report: Exploring the Disconnect Between Rated and Field Performance of Water Heating Systems

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Unless otherwise noted, all tables were created by the ARBI team.

Definitions

ARBI	Alliance for Residential Building Innovation
BA-PIRC	Building America Partnership for Improved Residential Construction
CARB	Consortium for Advanced Residential Buildings
DEG	Davis Energy Group
EF	Energy Factor
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
LBNL	Lawrence Berkeley National Laboratory
PARR	Partnership for Advanced Residential Retrofit

Acknowledgements

The Alliance for Residential Building Innovation Team appreciates the participation of the attendees and the presenters at the September 28, 2012 expert meeting. A special thank you to the presenters listed below:

Jay Burch, NREL

Carlos Colon, BA-PIRC

Paul Glanville, PARR

Dave Kresta, NEEA

Ben Larson, Ecotope

Jim Lutz, LBNL

Ben Schoenbauer, NorthernStar

Carl Shapiro, CARB

Eric Wilson, NREL

1 Introduction

Water heating represents a major residential energy end use, especially in highly efficient homes where space conditioning loads and energy use has been significantly reduced. Future efforts to reduce water heating energy use requires the development of an improved understanding of equipment performance, as well as recognizing system interactions related to the distribution system and the fixture use characteristics. By bringing together a group of water heating experts, we hope to advance the shared knowledge on key water heating performance issues and identify additional data needs that will further this critical research area.

2 Logistics

The expert meeting, "Exploring the Disconnect Between Rated and Field Performance of Water Heating Distribution Systems" was held on September 28, 2012, at NREL's Research Support Facility in Golden, Colorado. The meeting location was selected, in part, to facilitate the attendance for key NREL staff, as well to shorten travel for those attendees from the eastern or central United States. The full list of attendees is included in Table 1.

Table 1. Expert Meeting Attendees.

Attendee	Organization
Charlie Adams	AO Smith
Jay Burch	NREL
Carlos Colon	BA-PIRC
Cheryn Metzger	NREL
Paul Glanville	PARR
Marc Hoeschele	ARBI
Russ Johnson	Johnson Research
Gary Klein	Affiliated International Management
Jim Lutz	LBNL
Steven Ly	Sempra
Jeff Maguire	NREL
Rick Pal	Air Generate
Dave Roberts	NREL
Stacy Rothgeb	NREL
Harvey Sachs	ACEEE
Ben Schoenbauer	NorthernStar
Craig Selover	MASCO
Carl Shapiro	CARB
Elizabeth Weitzel	ARBI
Eric Wilson	NREL
Non-attending presenters	
Dave Kresta	NEEA
Ben Larson	Ecotope

3 Research Questions

The following key research questions were identified in advance of the expert meeting:

1. What are the impacts of actual use conditions on annual water heater energy consumption and how does it vary with water heater type, use patterns, and climate factors?
2. What specific information is needed to better understand field performance variation from test data for different common and emerging residential water heaters?
3. What are the maintenance needs for different water heaters and the potential performance degradation impacts over time? What testing should be completed to support this research area?
4. Are there trends in hot water usage and appliances that will contribute to changes in the performance variation or degradation of different water heating technologies?
5. How capable is BEopt, and other water heating simulation tools, in modeling the factors that contribute to performance variations in the field?
6. What additional research studies are needed to improve our understanding in this area and provide the needed data to enhance simulation models?

4 Objectives

The main objective of this expert meeting was to bring together a group of experts intimately involved with issues related to assessing the performance of residential high efficiency water heating systems. The expertise of the group included lab and field monitoring, model development, energy efficiency advocates, and manufacturers that are developing new and improved equipment options. Combining such a group of experts with diverse viewpoints and experiences allows for the opportunity to move toward consensus in particular technical areas, as well as identifying additional needs in terms of data, model development, or product capabilities.

5 Agenda

The meeting agenda and schedule are shown in Table 2. Each session included a 5-10 minute question and answer period.

Table 2. Meeting Agenda.

Time	Topic	Speaker
8:15 AM	Welcome and Introduction	Marc Hoeschele, ARBI
8:30 – 9:00	Hot Water Usage Patterns and Implications for Water Heater Performance	Jim Lutz, LBNL
9:00 – 9:30	Using Ratings Data to Predict Field Performance of Residential Water Heaters	Jay Burch, NREL
9:30 – 10:00	Laboratory Testing of Conventional and Advanced Water Heaters	Carlos Colon, BA-PIRC
10:00 – 10:30	Lab Testing of Advanced Gas Storage and Tankless Water Heaters	Paul Glanville, PARR
10:30 – 11:00	Field Monitoring of Advanced Gas Water Heaters in Eighteen California Homes	Marc Hoeschele, ARBI
11:00 – 11:30	Installed Performance of Water Heaters and Combination Systems	Ben Schoenbauer, NorthernStar
11:30 – 12:00	Heat Pump Water Heater Modeling and the Impact of Draw Profiles	Carl Shapiro, CARB
1:00 – 1:30	Heat Pump Water Heater Field Testing and Modeling in the Northwest	Dave Kresta, NEEA and Ben Larson, Ecotope
1:30 – 2:00	Prioritizing Future BEopt Water Heater Model Enhancements	Eric Wilson, NREL
2:00 – 3:00	Next steps, action items	Marc Hoeschele moderating

6 Presentation Summaries

The following provides a short summary of each presentation and the resulting discussion.

6.1 Hot Water Usage Patterns and Implications for Water Heater Performance

Jim Lutz presented on the hot water use database that he has been building over the past few years. The database includes high resolution field-monitored residential hot water usage data, with logging intervals of one minute or less. Longer time step data, such as 15-minute or hourly data, is not useful in understanding hot water patterns, since one datapoint may include multiple draws and the draw event cannot be accurately characterized if it is shorter than the logging interval. Most of the collected data from the 11 studies in the database has a logging interval of ten seconds or less. The database currently holds nearly 18,000 total days with quality monitoring data (totaling 865,000 hot water draws).

Jim provided a comparison of the data to the assumptions used in the Energy Factor (EF) test. The EF test prescribes six hot water draws separated by one hour, followed by 19 hours of water heater recovery and standby. Each hot water draw is at a flow rate of 3.0 gpm, with a total volume of about 10.7 gallons. Clearly, the EF test was not originally developed to mimic real usage patterns, although the 64.2 gallon/day total use was intended to represent typical daily usage volume. Overall daily use in the database is less than 51 gal/day, although the observed water heater inlet to outlet temperature difference is generally lower than the 77°F recognized in the EF test (58°F inlet, 135°F outlet). The average number of draws was in the neighborhood of 60 /day, although this overestimates actual draws since pressure fluctuation in the system often recorded phantom draws. Average draw volume size was between 0.1 and 0.2 gallons, and 85%-90% of the draws were 4 minutes or less. View the full presentation.

Conclusions:
The primary conclusion is that real world residential hot water use shows stark differences with the EF test in terms of usage quantity, flow rate, draw duration, and number of draws. Future water heater test procedures should better reflect realistic behavior, if we want to better represent the field performance of water heaters. Tankless water heaters are sensitive to time between draws, whereas this is mostly irrelevant for conventional storage tank water heaters. However, tankless water heaters are not very sensitive to daily draw volume, whereas storage tank water heaters are.

Discussion:
The implication of real world draw patterns will have an impact on water heater performance. Higher than "typical" recovery loads assumed in the EF test will tend to increase the performance of storage water heaters, since standby losses, as an overall loss component, are de-emphasized. Similarly, the six, large volume draws in the EF test results in higher than observed tankless performance, since it minimizes the inefficiency associated with the thermal cycling of the heat exchanger (capacitance effect). It would be useful to use the database to look closely at time intervals between draws.

The EF test may have been (and may still be) appropriate for testing storage water heaters, but the advent of tankless and HPWHs (which are very sensitive to patterns and use intensity) requires a new approach in the testing methodology to better capture real performance.

6.2 Using Ratings Data to Predict Field Performance of Residential Water Heaters

Jay Burch presented on the need for developing simplified models that can be driven by available ratings data. These simplified models are valuable for developing fairly robust annual performance estimates.

Storage tank water heaters

- Key parameters inferable for simulation and algebraic models
- Good simulation and algebraic models exist

Tankless water heaters

- One parameter inferable, others must be gotten elsewhere
- No algebraic model exists

Heat pump water heaters (HPWHs)

- No parameters inferable

- No algebraic model exists

Solar water heaters

- No parameters inferable
- Empirical algebraic model exists.

View the full presentation.

Conclusions:
Jay Burch pointed out that the general consensus that field water heater efficiencies are lower than rated is not surprising given that for most field studies with storage water heaters, the observed loads are lower than the EF test standard, and the performance impact due to reduced loads is well documented. Similarly, tankless water heaters demonstrate the impact of real world load patterns and therefore operate at lower efficiencies than indicated by the six large hot water draws in the EF test. This indicates a need for simple models that can be driven by available test data. While storage tank water heaters and tankless water heaters can be reasonably modeled with available data, HPWHs and solar water heaters are considerably more challenging.

Discussion:
Charlie Adams of AO Smith pointed out that manufacturers are limited by the Federal Trade Commission as to what information they are allowed to publicly provide. Additional data that may be of value to the research community is currently off limits for public consumption. The legislation directing DOE to revise the test procedure appears to give the opportunity to publish more useful information, such as the measured tank UA and volume.

6.3 Laboratory Testing of Conventional and Advanced Water Heaters

Carlos Colon of the BA-PIRC team presented on ongoing lab testing that the team is running at their Hot Water System lab at Cocoa, Florida. His presentation focused on test results from recent testing that included a 2.35 EF HPWH, both a 0.83 and 0.94 EF tankless water heater, a 0.59 EF atmospheric 40 gallon gas storage water heater, and high efficiency systems combinations that include solar water heating and either a HPWH or a condensing gas tankless unit. The testing used a 120°F setpoint in all cases, and looked at two hot water usage profiles (a 64.3 ASHRAE profile, and a Building America profile that includes seasonal usage affects associated with cold water temperature fluctuations). View the full presentation.

Conclusions:
Water heaters operated at a lower efficiency compared to their EF rating due to hot water demand schedule and seasonal variation of inlet water temperatures (note: summer inlet water temperatures exceeded 85°F, resulting in mid-summer daily hot water loads as low as 13,000 Btu/day, or less than one-third of the EF test level.)

Integration of high efficiency systems with solar thermal components demonstrate lowest daily energy use, but at a premium price. Improved temperature control strategies are needed.

Condensing gas tankless (EF= 0.94) demonstrated a 31% gas reduction over baseline but operated at 16% lower efficiencies during summer period (COP 0.75)

HPWH's provide a considerable step up in efficiency, however recovery takes longer compared to conventional heaters. (Industry to further develop 60- and 80-gal. models?)

Discussion:
BA-PIRC's testing of high efficiency hybrid systems (various solar + HPWH configurations) indicated that the incremental solar savings do not justify the added incremental cost in the central Florida climate. The lab test house resembles the daily thermal patterns of a garage, with very high environmental temperatures mid-days in the summer. Clearly this boosts performance. Studying interior HPWH performance in hot climates is of primary interest, both in terms of HPWH performance (relative to garage or outdoor closet location) and also in terms of space conditioning impacts.

6.4 Lab Testing of Advanced Gas Storage and Tankless Water Heaters

Paul Glanville of the PARR team reported on lab testing results of gas storage and tankless water heaters that was completed by GTI and subcontractor Pacific Gas and Electric under a GTI/CEC PIER project. The focus of the testing was to better understand the performance of advanced gas water heaters under controlled lab conditions. This included monitoring of parasitic energy use, performance under varying load conditions, and for tankless water heaters, assessing start-up characteristics and performance under transient hot water loads (response time and temperature stability). View the full presentation.

Conclusions:
Storage technologies (operated under typical California gas/electric rate assumptions) demonstrated lower than anticipated operating cost savings potential, partly due to parasitic electric consumption which varied from 0.07 to 0.42 kWh/day.

One hybrid storage product on the market was found to have fairly high standby use, both gas and electrical. Whereas most atmospheric gas storage water heaters have a fairly wide deadband, this unit has a tight deadband, resulting in three firings during the standby period of the EF test (storage units had zero firings).

Tankless technologies demonstrated different control systems in both the initial firing sequence and to changes in hot water flow rate. These different control sequences affect the delivery temperature and the time required to achieve steady state temperatures.

Some tankless units use an "active standby" mode to better respond to draws that are within a few minutes of one another.

Discussion:
Overall energy savings of these advanced units is lower than expected by the EF rating, and the economics can be compromised by the electrical parasitics, especially in areas like California, which has relatively cheap natural gas and expensive electricity. Tankless performance and delivery characteristics are important to know and may have implications in terms of customer acceptance, as sales move from early adopters to the broader market.

6.5 Field Monitoring of Advanced Gas Water Heaters in Eighteen California Homes

Marc Hoeschele of the ARBI team presented on findings from an 18-home field monitoring study that monitored the performance of both the existing atmospheric gas water heaters (pre-retrofit) and the retrofitted advanced gas water heaters (including 0.67-0.70 EF ENERGY STAR water heaters, condensing and non-condensing tankless units, and condensing storage water heaters) over a 12-month period. The work was a component of a larger CEC PIER sponsored project, managed by GTI. The presentation focused on the performance of the various classes of water heaters, the observed hot water loads, and the implications of the loads and California climate (mild inlet water temperature) on the performance of different product types. View the full presentation.

Conclusions:

Monitored California household recovery load (energy leaving the water heater) at the 18 homes was found to be one-third lower than the EF test level, despite the fact that average household size (of 3.6 occupants) was about one-third higher than census averages. The primary factor at play is mild cold water temperatures, as well as lower volumetric hot water use. The impact of the lower load on standard atmospheric water heater performance translates to a 13% reduction in field performance vs. rated.

ENERGY STAR storage (0.67-0.70 EF) and condensing storage water heaters saw similar degradation characteristics at low recovery loads. Tankless water heaters were much less affected by load, although performance was lower than rated.

When the performance data was reconciled with the EF recovery load level, the observed field performance matched well (±3%) for standard atmospheric and ENERGY STAR (0.67-0.70) storage water heaters. Non-condensing tankless variance of 10% at the EF load level is consistent with 2010 Minnesota field results. Condensing tankless variance from the EF rating of 16% was observed.

Parasitic electrical consumption for all these advanced water heaters is a concern, especially in states where gas is relatively cheap and electric is expensive. Annual projected usage is typically in the range of 80-100 kWh, but varies between the different products.

Discussion:

High efficiency water heaters for low load situations meet an important need for the energy efficiency community. Expectations are that loads will be lower in the future as more efficient showerheads and appliances are installed. Tankless water heaters may be the answer, but identified performance issues (cold start delays, cold water sandwich, etc.) and uncertain maintenance needs are a concern.

Jay Burch raised the issue that the input-output approach for tankless water heaters may introduce some inaccuracy in terms of defining the intercept, since very low load draw events will show a lower efficiency.

6.6 Installed Performance of Water Heaters and Combination Systems

Ben Schoenbauer of the NorthernStar team presented ongoing field data from the monitoring of 20 forced-air combined hydronic installations in Minneapolis. The study completed both preand post-retrofit monitoring, with a careful lab study looking at how to optimize system performance through control of component selection, system airflow, and coil flow rates. Ben discussed the status of combi system ratings and how different standards (ASHRAE 124, ASHRAE 118.2, and ASHRAE 118.1) treat systems differently. Ben also reported on recent testing of tankless and storage water heaters at 10 homes in Minneapolis. View the full presentation.

Conclusions:
Preliminary data suggests 10%-15% space and water heating savings can be realized (vs. 80% AFUE furnace and standard atmospheric gas storage water heater), provided that the systems are installed with proper coil water flow and airflow to achieve condensing operation.

Combi rating methods need to be developed to accurately characterize performance.

Standby losses associated with various systems can be high. Selection of combi system components is critical to insure that potential savings are not eroded by standby effects.

The 2010 tankless/storage water heating field test found that both tankless water heater and storage water heater installed efficiencies fell below their rated values. Storage water heaters are more sensitive to load (or volume) while tankless water heaters are impacted by short and intermittent draws. (The comparative performance of the water heaters in this study and the DEG GTI PIER study was found to be very similar.)

Customer satisfaction was fairly high for the tankless units with 9 of the 10 sites keeping the tankless unit at the end of the test. No clear statistically valid indication that households used more hot water with the tankless than with the storage, although changes in usage pattern were evident (similar result as observed in DEG GTI PIER project).

Discussion:
Industry education will be an important point of emphasis to insure that contractors are installing systems in a manner in which efficiency potential can be realized.

Inlet water temperature has implications on load and performance of the forced-air combined hydronic systems. Significant variations were observed at the Minneapolis sites due to water source (well vs. surface) as well as basement winter "pre-heating" effect.

6.7 Heat Pump Water Heater Modeling and the Impact of Draw Profiles

Carl Shapiro of CARB presented on the development of a HPWH model derived from field data collected at 14 residential HPWH monitoring sites in the Northeast. The presentation focused on the data analysis and the development of a first principles model driven by inputs including ambient temperature and relative humidity, setpoint temperature, mains temperature, and hot water profile. The modeling effort is still underway. View the full presentation.

Conclusions:
Modeling is challenging, especially reflecting the impact of load patterns with the control system.

Discussion:
Understanding of control systems is challenging, and manufacturers are updating control strategies. HPWHs represent a modeling challenge because control strategies vary among the different manufacturers and the performance map is complicated by the staging from heat pump operation to resistance heat operation. More data is needed on the different products on the market for use in model development.

6.8 Heat Pump Water Heater Field Testing and Modeling in the Northwest

Dave Kresta of NEEA and Ben Larson of Ecotope presented on HPWH activities that are underway in the Pacific Northwest. Dave mentioned that field testing of 30 Tier 2 HPWHs is ongoing and will continue into 2013 (15 units in conditioned space with ducting kits, and 15 in garages or basements). Preliminary results suggest 30%-60% energy savings, with COPs ranging from 1.5-2.0 for garage/basement units, and 1.7-2.4 for units in conditioned space. Ben Larson presented on development of a simple HPWH model that is based on a limited set of input parameters. The model uses 12 stratified tank nodes and a 1-minute time step. NEEA field data was used to see how well it matched the model. To calibrate to the field results, HPWH COP curves and control strategy refinements were used to improve the match. View the full presentation.

Conclusions:
In the HPWH modeling, it was determined that a 10%-15% reduction in the COP curve was needed to match the field data. The current thinking is that the tank stratification effects and condenser heat transfer characterization are the primary factors affecting performance.

Discussion:
Next steps for the work include extending the modeling to other HPWH products, developing a more generalized approach for predicting field performance, and extending the model to assess whole house (space conditioning) interactions. Marc Hoeschele mentioned ongoing work that is occurring in Canada on assessing HPWH space conditioning impacts.

6.9 Prioritizing Future BEopt Water Heater Model Enhancements

Eric Wilson of NREL presented on current BEopt water heating modeling capabilities, and also potential areas of improvement and enhancement. Currently, BEopt models:

- Gas and electric storage (single node tank with rated EF, recovery efficiency, and calculated tank UA)
- Gas tankless (both condensing and non-condensing have an 8% cycling degradation, as per California Title 24 assumptions)
- HPWHs (NREL hourly model using EnergyPlus)
- Solar systems (EnergyPlus with stratified solar tank).

Distribution system model accounts for heat gains to semi-conditioned space, but does not account for the impact of recirculation on HPWH or condensing tankless performance.

Potential areas of model development include condensing gas storage systems, combined hydronic systems, drain heat recovery, and ducted HPWH systems. Improvements include accurately accounting for parasitic electric use for both gas and HPWH systems (including tankless freeze protection), adjusting tank standby losses to reflect heat up the flue, and improved modeling of tankless cycling degradation. View the full presentation.

Discussion:
Ben Schoenbauer indicated a simple combined hydronic model would be the appropriate first step for model development in that area. More validation work on alternative HPWHs (current EnergyPlus model is based on the GE unit) is needed, especially as control strategies change. HPWHs are recognized as being challenging to model, given the variations in configuration and control strategy.

7 Research Question Follow-up

This section provides a summary of what was learned in each topic area.

1. ***What are the impacts of actual use conditions on annual water heater energy consumption and how does it vary with water heater type, use patterns, and climate factors?***

This is an area that has received much attention in the past few years, but more effort is needed. The LBNL hot water database contains data from studies that were predominantly completed in older existing homes. New homes are likely to have lower end use loads (lower flow showers and faucets, more water efficient appliances), but possibly higher distribution losses. Additional data are needed to address this question. Climate plays a bigger than anticipated role in hot water recovery loads, as several recent studies have identified cold water temperatures that are significantly warmer than commonly assumed by analysts. The mains water temperature algorithms developed at NREL is a good starting point for estimating mains water temperature at any location. This has implications in terms of hot water recovery load, and potentially on user behavior, as "warm climate" households may have hot water needs in the winter that disappear in the summer (i.e. bathroom sink use). Getting the seasonal use profiles right is important, since it has significant bearing on the performance of technologies that are sensitive to seasonality, for example, HPWH and solar thermal.

2. ***What specific information is needed to better understand field performance variance from test results for different common and emerging residential water heaters?***

In understanding the performance of emerging high-efficiency water heaters, we need to distinguish between potential performance degradation that may occur over time, and how real world usage patterns affect the equipment's rated performance. Concerning real degradation, longer term monitoring is needed on many technologies, especially HPWHs and tankless water heaters, which may be susceptible to degradation over time if proper maintenance is not undertaken. (Storage water heaters are fairly robust technologies as documented in a 2012 Navigant test of a variety of units that had been in use from 2-14 years[1].)

[1] http://www.aceee.org/files/pdf/conferences/hwf/2012/5B-Goetzler-Final.pdf

Utilities can and should play a central role in this effort, since they have connections to their customers through rebate programs. Understanding tankless water heater and HPWH performance over time would be the key areas of interest. This implies keeping monitoring hardware in place over an extended period of time, since capturing performance of these systems involves more than an instantaneous assessment, such as for an air conditioner. Accelerated lab testing is another approach that could be implemented. The questions that need to be answered include:

- Is there hardware degradation over time that degrades performance?
- Under what conditions is degradation observed?
- How commonly does this occur?
- What component(s) contribute to the degradation?
- What fixes can be implemented and how much does it cost to remedy the situation?

3. ***What are the maintenance needs for different water heaters and the potential hardware performance degradation impacts over time? What testing should be completed to support this area***?

Maintenance for standard gas and electric resistance storage water heaters is rarely completed with apparently minimal adverse effects to performance. Tankless water heaters are much more prone to scaling in hard water environments. To date, only anecdotal data exists that suggests how big a problem this is, and what the impacts are when little or no maintenance is performed. This data will be challenging to get from industry, although individual plumbing contractors may be willing to share information on their maintenance experiences. A potential source of information in this area is from utility companies that are running rebate programs for tankless water heaters.

HPWHs also require some level of maintenance. One common maintenance procedure is cleaning of the evaporator air filter. As the filter collects airborne debris, it will start to restrict airflow and reduce system performance. Again, utility partners and groups like NEEA might be good resources to contact regarding this issue. Lab and/or field monitoring could be used to evaluate the performance implications of reduced airflow.

4. ***Are there trends in hot water usage and appliances that will contribute to changes in the observed field performance of different water heating technologies?***

Most water heaters are sensitive to usage patterns and overall usage quantity. Storage water heaters are highly influenced by daily recovery load, but daily efficiency is not very dependent on how many draws and how much time between draws. Tankless water heaters and HPWHs are much more sensitive to load patterns, load intensity (gallon/minute), and time between draws. HPWHs, in particular, are significantly influenced by load intensity, since these units have a binary heating efficiency (>200% when in HPWH mode, 100% when in electric resistance mode). A range of factors should reduce future water heating loads, including:

- More efficient appliances (horizontal axis clothes washers

- More water efficient dishwashers
- The advent of cold water clothes washing
- Reduced showerhead flow rates (and improved customer acceptance)
- A greater emphasis on distribution system performance in upcoming energy codes. This effect will reduce average water heating loads, contributing to further disconnect between field and test data in storage water heater performance (gas, electric, and HPWH), and also tankless (to a lesser degree).

The advent of hybrid water heaters that combine tankless features with a small (15-25 gallon) storage tank, may be a solution to achieving improved efficiencies in the future.

5. ***How capable is BEopt, and other water heating simulation tools, in modeling the factors that contribute to performance variations in the field*?**

BEopt can currently adequately model storage gas and electric resistance water heaters. HPWH modeling capabilities using the EnergyPlus model have been developed and demonstrated to provide very good agreement with field data for the GE unit. However, BEopt's ability to accurately model other unit configurations and ongoing control modifications to new and existing systems suggest that this area is a moving target. In addition, performance impacts related to HPWH operation in enclosed spaces, HPWH space conditioning impacts and ducting systems, humidity impacts, and evaporator coil icing are all not currently handled well by many analyses. Some models have married building models to HPWH models to address this issue, such as the recent NREL study. NREL needs to determine the level of effort required and prioritize these HPWH upgrade options. It is possible that work being completed by Ben Larson at Ecotope might also support this effort.

Tankless gas water heaters are handled simplistically (8% fixed EF degradation), but accurately, at least for non-condensing units (there is fairly strong evidence that condensing tankless performance should be derated further). Developing a more sophisticated first-principles-based, tankless model would improve the overall accuracy, but it may not be a high BEopt update priority and also has run time implications. Marc Hoeschele mentioned that the existing first-principles TWH models run too slowly for BEopt, and so are not yet incorporated. The development needed is to make these models run in seconds instead of minutes, which can be done. Better characterization of hot water loads, load patterns, distribution system impacts, and cold water inlet temperature effects (pre-heating or pre-cooling by building unconditioned spaces) are all areas that need further effort. It is very clear that we are not yet adequately representing "real world" peak load events and the clustering of draws to accurately capture performance impacts on HPWHs (and clear that we do not know how to do that yet.)

Finally, combined hydronic system modeling within BEopt should be a high priority, given the level of interest that currently exists in the technology. A simplistic model would probably be the first step, since a rating method does not yet exist for these systems. Characterizing the performance of condensing water heaters with combined systems (i.e. airflow, coil sizing, and coil water flow) is an important consideration, but may be beyond the scope of initial modeling efforts.

6. *What research studies are needed to improve our understanding of this issue and provide the needed data to enhance simulation models*?

As summarized above, more effort needs to be expended to collect data that builds on our understanding of system performance characteristics, water heater controls (with a focus on HPWHs), and representative hot water loads, especially in new, more efficient homes. The availability of data from these studies will play a key role in driving future model development activities. At this point, there seems to be sufficient data on characterizing performance of storage gas and electric water heaters. Some participants felt that more testing is needed on tankless units to develop a broader understanding of the distribution of tankless water heater parameters, while others feel that there is sufficient data to adequately characterize performance. Recently introduced hybrid gas water heaters also need further evaluation.

Key areas of future effort include:

HPWH: Are the control characteristics of other HPWHs, as reflected in field monitoring studies, adequately represented by the current BEopt model? If not, can we use the existing model to validate to other datasets and develop recommendations to users on how to model different system types (or product classes)? Additional lab and field testing is needed as new HPWHs come to the market, or as control systems are modified.

Hot Water Loads and Patterns: Improved data on "new home" hot water loads and the seasonality of hot water use should be collected and evaluated to determine if simulation models are accurately reflecting "typical" loads. The seasonality issue is most significant for those technologies that exhibit performance variation with temperature (or insolation, such as solar thermal). Seasonality effects can be characterized as 1) the impact of the cold water temperature on mixed hot water events (how much hot water relative to cold is needed), and 2) seasonal variation in the use of tempered water or fixed draw volume, such as less showers or cooler showers or shorter showers. (It is not clear that this is significant, but little data exists in this area). A final comment on hot water use behavior is how new technologies will affect how people use hot water. Tankless water heaters have been observed in several studies to result in distinct differences in hot water usage patterns. What about other technologies such as HPWHs, drain heat recovery, demand recirculation distribution systems, etc.?

Distribution System Performance: Understanding of distribution system performance and its impact on overall water heating loads is an area that needs further study. Several limited field studies are underway, as are efforts to develop and validate detailed distribution system models. Loads and use patterns are a key driver to assessing distribution system performance, so this area is highly linked with other research needs. A complicating factor in integrating enhanced distribution system modeling into BEopt and other hourly tools is the fact that detailed hot water system modeling tools operate on much shorter time steps than building energy simulation models.

8 Action Items

The main goal of this meeting was to bring together experts in the water heating arena, including researchers, manufacturers, energy efficiency advocates, and utility personnel. The assembled group provided lively discussion and generated opportunities for future data collaboration on ongoing research activities.

Key action items include:

1. Continue to provide input to the U.S. DOE and ASHRAE TC118.2 as they work towards finalizing a revised water heater test procedure.

2. Support continued HPWH monitoring efforts to assess new product offerings and control systems and determine if existing models properly capture field performance.

3. Provide input to the Air-Conditioning, Heating, and Refrigeration Institute on the need for expanded water heater rating data.

4. Coordinate with utilities and groups running water heater rebate programs to gather and share data on advanced water heater maintenance activities.

5. Work with NREL as future BEopt water heating enhancements get prioritized and implemented.

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