REVISED VERSION

The UK heat pump field trial: findings from phase 2

Jaryn Bradford
MA *AIEMA*
Energy Saving Trust
21 Dartmouth Street
London, SW1H 9BP
UK
jaryn.bradford@est.org.uk
+44 (0)207 227 0355

Tom Byrne
Energy Saving Trust
21 Dartmouth Street
London, SW1H 9BP
UK
tom.byrne@est.org.uk

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Abstract

The Energy Saving Trust's heat pump field is the UK's most comprehensive study to measure the performance of in-situ residential heat pump installations. Running from 2008 until 2012, the study has collected performance data from 83 heat pumps – including 29 air source and 54 ground source – installed in a varied range of housing conditions in the UK. The findings from Phase 1 (2008–2010) of the field trial, presented at the eceee 2011 Summer Study (Bradford, et al, 2011), discussed the results from in-situ monitoring and provided a comparison of measured UK performance compared with similar European field trials. Phase 1 identified a wide range of performance results, with many (53) installations exhibiting 'poor performance' with annual SPF values below 2.5. Most of these sites were investigated further as part of Phase 2.

Phase 2 (2010–2012) undertook additional investigation to determine best practice design and installation of heat pumps in three steps: Firstly, UK installer standards were revised to encourage better design and installation. Secondly, interventions were undertaken at 32 field trial sites to determine if the performance of 'poor performing' installations could be improved by following new installation guidelines. Specific investigation was undertaken into areas such as heat pump sizing; heat emitters; and flow temperature. Finally, 38 heat pumps were monitored for a second year and results were compared to Phase 1 as a series of case studies. These heat pumps included 32 sites with interventions and 6 sites with no interventions as a 'control group'.

Results from Phase 2 illustrate that 21 sites undergoing interventions achieved improved performance with 11 performing similarly or slightly worse. This paper will present the measured in-situ performance across the sample for both Phase 1 and Phase 2; identify the interventions undertaken; and discuss the impact of interventions on performance (SPF).

Introduction to the field trial

The UK Government has recently been promoting the electrification of space and water heating as a key means to achieve carbon reductions in the residential housing sector. Research has been undertaken to demonstrate the impact that well performaing heat pump installations could have if installed with high penetration in the UK (DECC 2012). Such assumptions are based upon the premise that heat pumps will perform at a reasonable level of performance, generally assumed as achieving seasonal performance factors (SPF) in excess of 2.7. The field trial has therefore sought to determine the factors that impact heat pump and system performance.

The Energy Saving Trust's (EST) heat pump field has been measuring the performance of a sample of in-situ residential heat pump installations since 2008. The study is the UK's largest in-situ evaluation project for the technology, ranging over 4 years and 2 phases. Phase 1 monitored 83 heat pumps between 2008–2010 (EST, 2010) and phase 2 continued monitoring at 38 of the sites which were of significant interest, many determined as 'poor performing systems' with a number of good performing sites as a control group. The monitored heat pumps were installed in a varied range of housing conditions in the UK. The findings from Phase 1 were presented at the eceee 2011 Summer Study.

BACKGROUND TO PHASE 1

Phase 1 of the EST field trial was launched in 2008 in conjunction with the UK Department of Energy and Climate Change (DECC) and 6 heat pump manufacturers. The objective was to determine the in-situ Coefficient of Performance (COP) and Seasonal Performance Factor (SPF) of 83 residential heat pumps including 29 air source and 54 ground source installations in a cross-section of actual homes (Bradford, et al, 2011). The field trial demonstrated the actual performance, user experience, and carbon savings achieved from a sample of heat pumps. The results demonstrated a wide range of performance: the mean SPF was 2.2 for air source heat pumps and 2.3 for ground source heat pumps. The overall measured SPFs ranged from 1.2–3.2 for air source heat pumps and 1.3–3.3 for ground source installations respectively, which is well below the average of findings from similar field trials undertaken in Germany and Switzerland. In Germany an average SPF of 3.3 was measured for ground source installations and 2.6 for air source (Fraunhofer Institute, 2010). In Switzerland an average SPF of 3.4–3.5 was measured for ground source systems (Hubacher, et al, 2004).

Results from phase 1 suggested that a number of systems were either poorly designed or mis-sized, particularly the heat sink types and loads. It was also concluded that the control systems were too complex and that end-users were not able to effectively control their heat pumps, leading to poor system performance. 53 of the installations were deemed to be exhibiting 'poor performance' with COP and annual SPF values of below 2.5. It was agreed that a second phase of the field trial would further investigate the reasons behind poor and good system performance; identify interventions and monitor a sample of the heat pumps for a second year.

BACKGROUND TO PHASE 2

The second phase of the field trial began in 2010 by undertaking additional research into the perforance at each of the 83 field trial sites (DECC, 2012b). Meetings were held with the heat pump manufactures to thoroughly analyse phase 1 performance data to identify potential interventions to the sites. Possible interventions were identified at nearly every site and 38 of the original 83 sites were selected for additional investigation, based largely upon customer willingness to continue their participation in the study, but also because the sites had shown considerable good or poor performance in the first phase of monitoring.

A further outcome from the analysis of phase 1 data was a revision to the UK Microgeneration Installation Standard MIS3005.3[1], chaired by EST and DECC. A working group was formed to address and improve UK heat pump installer standards, based upon the findings from the field trial.This working group particularly focussed on addressing system design; sizing; and heat emitters.

Of the 38 sites participating in phase 2, 32 were identified to undertake interventions which were classified as either major, medium or minor. The remaining 6 sites were left as a control group with no interventions, thus illustrating the continued performance at a number of sites. The manufacturers facilitated the agreed interventions between Autumn 2010 and Spring 2011 to the new MIS3005.3 guidelines (DECC 2012c). Monitoring of these sites resumed in March 2011 and continued until March 2012.

In addition to the 38 sites carried over from phase 1, 6 new installations (all air source) were also monitored as part of phase 2. The 6 newly installed sites were all installed using the new MIS3005.3 guidelines. Monitoring of these 6 sites over a one year period aimed to investigate whether the new standards had achived results in ensuring improved system performance.

Methods for Phase 2

The monitoring methodology used in phase 2 was the same used for phase 1 of the heat pump field trials. Figure 1 illustrates the principle measurements undertaken at each site and Equation 1 and 2 illustrate the formulae used to calculate SPF.

EST's monitoring specification[2] required two principal types of energy measurement to establish the operating SPF of the heat pumps:

- The electricity consumed by the heat pump and any immersion heating elements (shown with the symbol E).
- The heat delivered to the space heating and hot water systems (shown with the symbol H).

Additional to these standard measurements, a selection of sites had additional monitoring equipment installed to reflect the intervention that had taken place at the site. Examples of additional monitoring that took place at a number of sites in phase 2 include:

- Additional heat meters added to ground loops.
- Electrical consumption of smart radiators monitored.
- Electrical consumption of additional pumps monitored.
- Heat meters added to heat pump output (missing from some phase 1 sites).
- Additional temperature sensors monitoring refrigerant circuits.
- Heat meters added to DHW tank coil circuits.

PHASE 2 INTERVENTIONS

Interventions took place at 32 sites in phase 2 of the field trial and each were categorised as major, medium and minor based upon a number of factors including the cost of the intervention, the work required, and the scale. In many cases sites were subjected to multiple interventions grouped in the same or multiple catergories.

The interventions undertaken at each site attempted, when possible, to utilise new installation procedures recommended by the improved MIS3005.3 standards which included new

1. The revised installer standards can be found on the UK Microgeneration Certification Scheme (MCS) website http://www.microgenerationcertification.org/admin/documents/MIS%203005%20a%20practical%20example%20v2.0.pdf.

2. The technical monitoring specification is availabe on the Energy Saving Trust's website at: http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Microgeneration-Renewables/EST-monitoring-specification-for-heat-pumps-ground-and-air-source.

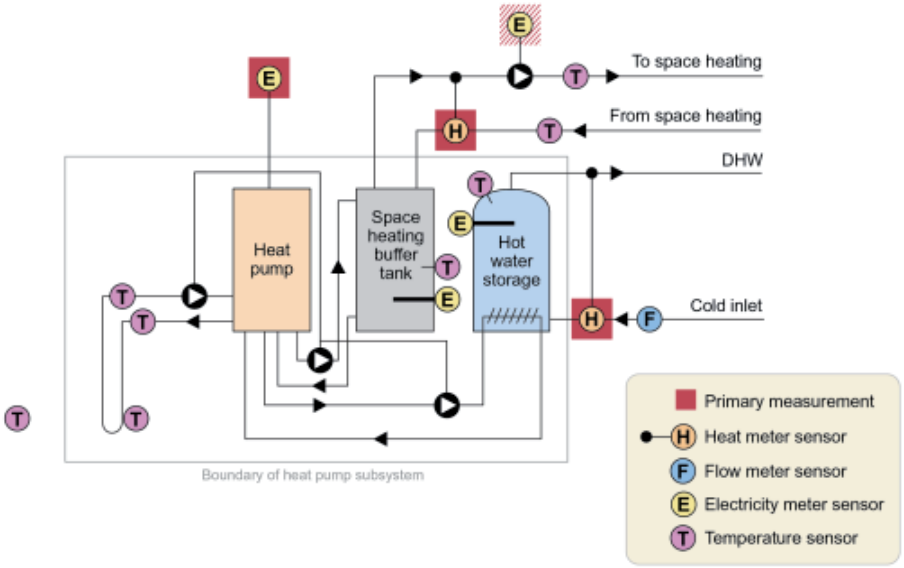

Figure 1. Measurements taken at a typical heat pump installation.

guidelines for sizing heat pumps and heat emitters based on the building's heat demand This led to the replacement of a number of heat pumps with smaller units in phase 2 to identify the impacts of sizing during the installation. The sites with new heat pumps installed to the new standard performed better than before, as illustrated in Figure 2 (major interventions). Monitoring of phase 2 sites enabled the project team to investigate the impact that these interventions and the revised installation procedures had on the sample compared with data from phase 1.

The number of interventions in each category can be found in Table 1. Table 2 lists five examples of the 'major' interventions undertaken. Table 2 illustrates a number of sites where heat pumps were replaced. Cycling was seen as a major reason for poor performance at a number of sites in Phase 1 of the trial and this was often attributed to heat pump over-sizing. Consultation with a number of manufacturers identified that cycling could be reduced by the installation of smaller heat pumps with buffer tanks to better match the buildings' designed heat load In most instances existing heat pumps were replaced with smaller units.

Results from phase 2

The findings from phase 2 provide useful insight into the impacts of the interventions undertaken at 33 sites compared with the 6 control group sites. The results from the in-situ monitoring illustrate that improvements to operating performance (SPF) were achieved at many sites and that had interventions, with only a few demonstrating poorer performance. Figure 2 illustrates how the interventions, classified by category (major, medium, minor interventions; no change) affected system performance across the sample[3]. Figure 2 illustrates that sites classified as 'minor' or 'no intervention' achived very small changes

3. Please note that COP could not be calculated for a small number of sites due to the inability to take specific measurements at these 6 sites.

$$SPF = \frac{DHW_{taps} + CH}{Electric_{HP} + Electric_{pumps} + Electric_{imm}}$$

Equation 1. The formula used to calculate SPF.

in measured SPF, due largely to seasonal weather variation or minor changes in controlling the system. Results from each of the major, medium, and minor sites are discussed in separate sections below.

RESULTS FROM MAJOR INTERVENTIONS

The major interventions had the largest impact on system performance with the majortiy of sites performing to a much higher SPF. This was result was expected because a majority of these interventions included a replacement of the heat pump, installed under the latest installation standards. For example, 10 sites had heat pumps replaced with new units (5 GSHPS and 5 ASHPS). In 5 cases the replacement heat pumps were sized to a smaller kW rating than the originals; 3 units were replaced with a larger kWh model; and 2 were swapped with a same size unit. Table 2 shows some examples of the major interventions taken.

Figure 3 illustrates the distribution of SPFs from sites with major interventions both before and after the intervention. The figure demonstrates that, whilst there still was a wide range of measured SPFs in phase 2, the distribution of results has also shifted to the right, demonstrating an overall improvent to the performance of the sample.

Table 3 includes the list of sites which had major interventions undertaken and illustrates whether the site was a ground or air-source installation and each site's pre/post intervention SPF. Nine sites achieved improvements in SPF; no sites had a notable reduction in performance. Two sites in particular did not achieve expected improvements, including sites 407

Table 1. Type and number of interventions in phase 2.

Type of intervention	Number	Explanation of intervention
Major	12	These interventions involve a complete change of system e.g. replacement of the heat pump or changes to the control panel.
Medium	9	These interventions include small physical changes to the system, e.g. buffer tank added, circulating pumps changed, voltage optimiser added etc.
Minor	11	All other interventions fall into this category, e.g. ground loop refilling, extra insulation, changing control parameters or an annual service.

Table 2. Examples of major interventions undertaken.

SITE ID	Type – source	Intervention
407	GSHP – borehole	Original 5 kW unit replaced with 6 kW unit. 150 l DHW tank replaced with new 125 l tank. 3 standard radiators replaced with fan assisted smart radiators.
414	GSHP – water	Original 10 kW unit replaced with 8 kW unit. Underfloor heating thermostat deployed.
418	ASHP+ Exhaust ASHP	Original 8 kW ASHP replaced iwht 6 kW unit. Original Exhaust ASHP also upgraded to newer model. 100 l buffer tank also added.
419	GSHP – 2 boreholes	Original 12 kW unit replaced with 8 kW unit. 200 l buffer tank added. Ground loop refilled.
423	ASHP	Original 8 kW unit replaced with 6 kW unit. Buffer tank reinstalled.

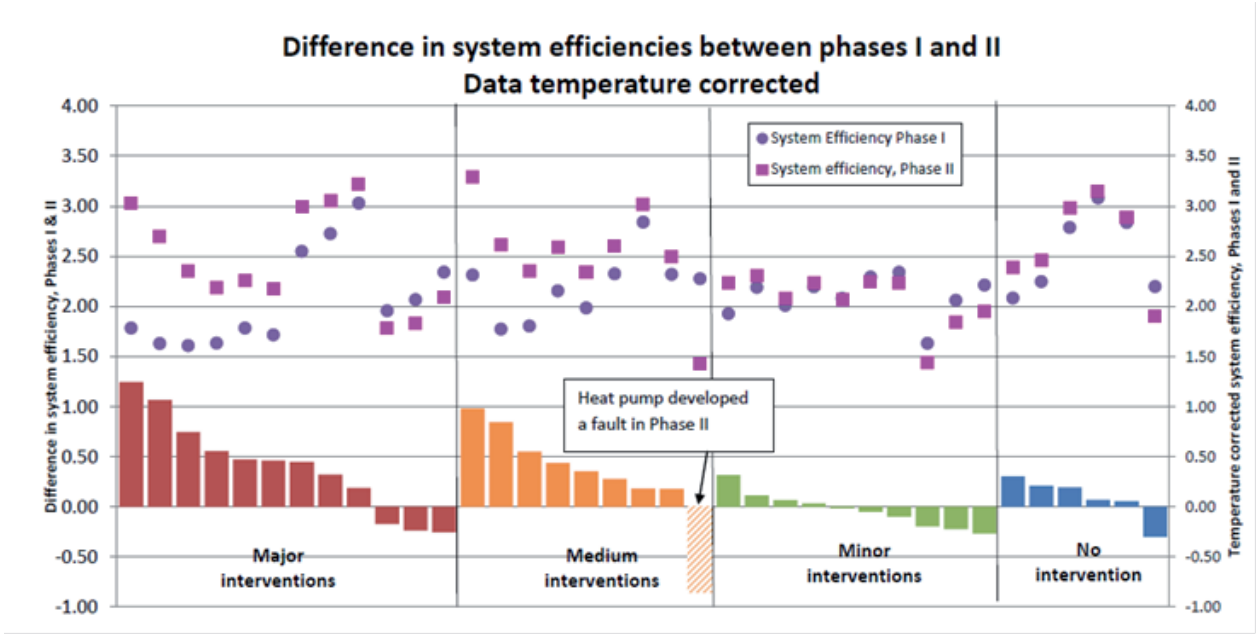

Figure 2. Distribution of changes to system SPF measured in phase 2.

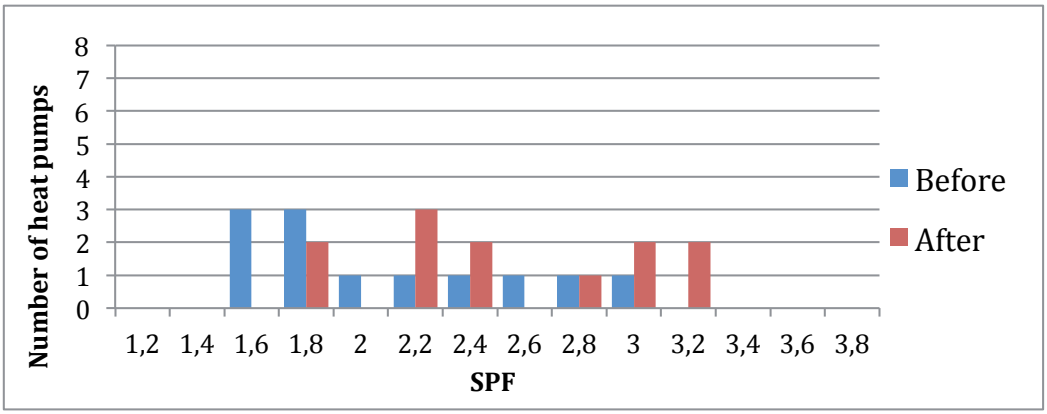

Figure 3. Distribution of before and after SPFs for sites that incurred major interventions.

Table 3. List of sites with major interventions with the pre/post intervention SPF.

Site ID	Type – Source	Pre intervenetion SPF	Post intervention SPF
407	GSHP – borehole	**2.07**	**1.83***
461	GSHP – borehole	**2.34**	**2.09****
444	ASHP	**1.63**	**2.19**
417	GSHP – trench	**2.55**	**2.99**
418	ASHP & ExAHP	**1.63**	**2.70**
419	GSHP – borehole	**3.03**	**3.22**
422	ASHP	**2.20**	**2.23**
423	ASHP	**1.96**	**1.73**
473	ASHP	**1.72**	**2.18**
414	GSHP – water	**2.73**	**3.05**
427	GSHP – trench	**1.78**	**3.03**
477	GSHP – borehole	**1.78**	**2.26**

and 461 (both borehole sites). For example, site 407 had smart radiators installed however the user turned the fans turned off which lead to very high flow temperatures (av. 52.6 °C) and poorer than expected performance (similar to phase 1) for SPF. Site 461 achieved a COP much higher than SPF because heat pump only delivered space heating. Hot water usage was provided by an immersion heater, which is included in our system boundaries for SPF.

RESULTS FROM MEDIUM INTERVENTIONS

Some of the sites with medium interventions produced equally improved system performances compared with major interventions. Eight sites showed improved performance in phase 2. Only one site with a medium intervention achieved a lower SPF in phase 2 (compared with phase 1). It became apparent that this system had developed a serious fault during phase 2 monitoring. This site is shaded in Figures 2 and 4.

Figure 4 illustrates the distribution of SPFs from sites with medium interventions both before and after the intervention.

RESULTS FROM MINOR INTERVENTIONS AND CONTROL GROUP

The minor interventions showed very little impact in heat pump SPF across the sample during the second year of monitoring. This indicates that such interventions including changes to customer control regimes and annual service checks caused little impact to seasonal impact if not combined with a major or minor or medium intervention, however these minor interventions may be important to maintaining performance over the lifetime of the system, beyond the one or two years monitored as part of this field trial. The impact of minor interventions over a period of time is beyond the scope of this study but would be an intersting area for additional research.

As expected the control group showed relatively similar results in phase 1 and phase 2. SPFs varied more than calculated COPs, again showing possible impacts of user behaviour of system performance.

RESULTS FROM NEW SITES

It was anticipated that the new sites (all air source) which were installed using updated installer standards would have better performance than the air source heat pumps monitored in phase 1. However, the SPFs ranged from 1.7 to 2.7, and 4 out of the 6 heat pumps had SPF less than 2.3, as shown in Figure 5. All of these sites produced both space heating and DHW and the tank losses were quite high for some of the sites, which is a potential explanation for the reason why these installations only performed slightly better than the sample of air source systems in phase 1. Two of these sites also included fanned radiators which consumed a large proportion of electricity.

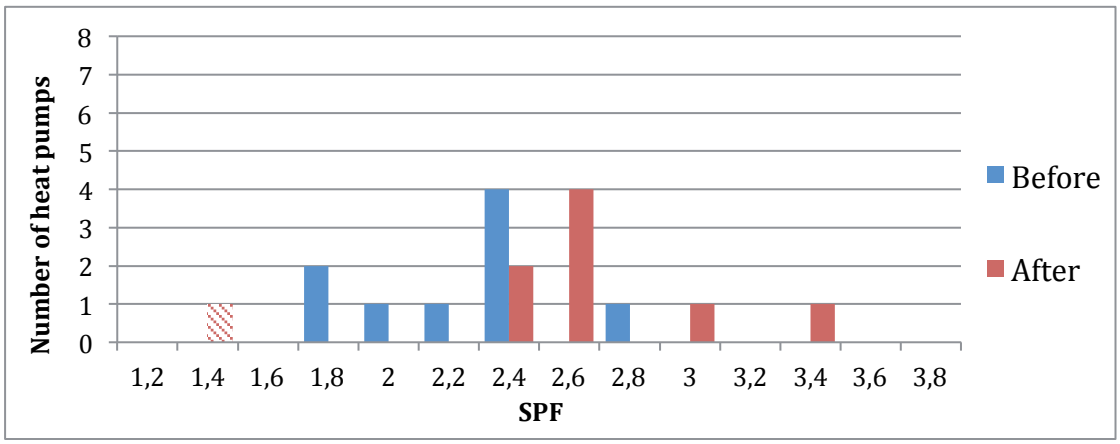

Figure 4. Distribution of before and after SPFs for sites that incurred medium interventions.

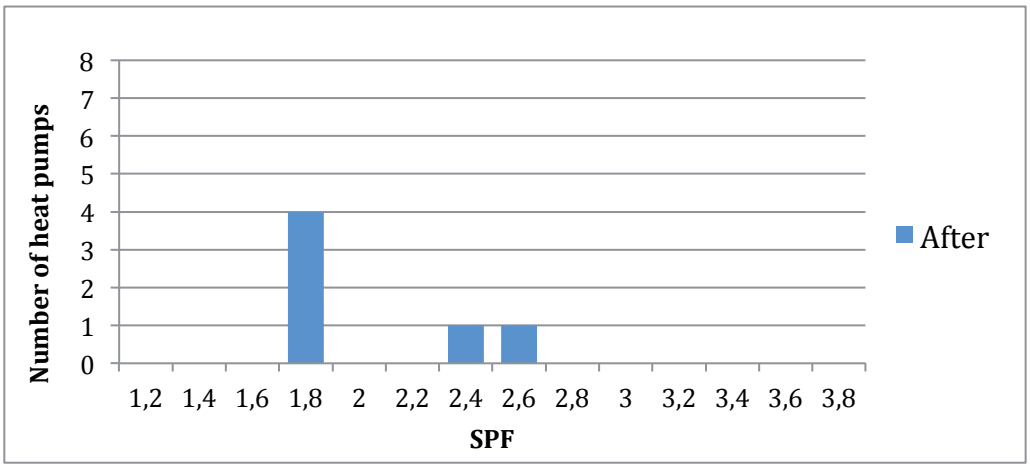

Figure 5. Distribution of SPFs for new sites (all air source) installed in phase 2.

Conclusions

The electrification of heat has been identified by the UK Government as a key approach to reduce CO_2 emissions from the residential sector. The Energy Saving Trust's heat pump field trial, which ran in two phases between 2008 and 2012, provides useful insight into the in-situ performance of the technology when installed in UK homes. Phase 1 illustrated that many of the monitored heat pumps did not perform as well as anticipated. Phase 2, through the results presented in this paper, indicates that a number of interventions including appropriate sizing and applying the new installation standards, can result in improvements to the performance of both ground and air source systems. This supports the premise that improvements in heat pump installation practices, following the new MIS 3003 installer guidelines, should lead to better in-situ performance. The largest improvements were measured in sites that had 'major' interventions, including redesigns of heat pump installations to the new standard. Minor interventions, including changes to control regimes and annual service checks, had minimal impacts on monitored system performance. This suggests that heat pump performance has the potential to improve as the UK market continues to evolve and adopt more rigorous installer standards.

Although this field study is the largest undertaken in the UK to date, as with similar European studies there were a variatey of different dwellings, users and heat pump systems evaluated. Further research into the perfornance of residential-scale heat pump installations must be undertaken to better identify the impacts of performance is specific housing build types and with different user groups.

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