

Final results from IEA HPT Annex 52 - Long-term performance of large GSHP systems

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ABSTRACT

Annex 52 - the international collaboration project on long-term performance of larger ground-source heat pump (GSHP) systems initiated through the Heat Pumping Technologies (HPT) technical collaboration program (TCP) of the International Energy Agency (IEA) in 2018 - was completed in December 2021. The aim of this IEA Annex was to analyze monitored long-term performance data from a variety of GSHP systems serving commercial, institutional, and multi-family buildings in the seven participating countries. To account for the variation and complexity of large GSHP systems, an extended system boundary schema, based on the SEPEMO schema, was developed, and used within Annex 52.

29 large GSHP performance-monitoring case studies, located in Sweden, Norway, Finland, Germany, the Netherlands, the UK, and the USA have been analyzed and reported. Performance factors and other system efficiency indicators for relevant time frames and system boundaries were determined. The experience from the included case studies have resulted in guideline documents for instrumentation and monitoring, as well as for uncertainty calculations and performance analysis and reporting. These documents will be of help for future GSHP projects, system optimization and fault detection. This paper provides a summary of the outcomes and results from Annex 52.

1. INTRODUCTION

Field measurements of building heating and cooling system performance are essential to ensure that performance expectations are actually met. For GSHP systems, owners have made significant investments with expectations of high performance, which makes it particularly important that high performance be achieved. Though some field measurements have been reported in the literature, there has been little or no consistency on how to measure the performance or how to report the results. Cost-effective measurement programs are hindered by this lack of consistency and a lack of guidance regarding measurement system design.

The international collaboration project IEA HPT Annex 52 - *Long-term performance monitoring of GSHP systems for commercial, institutional and multi-family buildings* was carried out between January 2018 and the end of December 2021. Seven countries participated in the Annex: Sweden (Operating Agent), the USA, the UK, the Netherlands, Germany, Norway and Finland. Annex 52 has aimed to survey and create a library of quality long-term measurements of GSHP system performance for commercial, institutional, and multi-family buildings, to refine and extend current methodology to better characterize performance of such systems with the full range of features shown on the market and provide a set of benchmarks for comparisons of GSHP systems around the world. This helps building owners, designers and technicians evaluate, compare, and optimize GSHP systems, and provides useful guidance to manufacturers of instrumentation and GSHP system components, as well as to developers of tools for monitoring, controlling and fault detection/ diagnosis. In the long run, this will lead to energy and cost savings.

This paper gives an overview of the results and outcomes from Annex 52, with focus on the ground heat exchanger efficiency. There is a lack of good measurements of ground heat exchanger efficiency and performance that quantify the heat transfer in relation to the pumping energy.

2. MONITORING PROJECTS

As part of Annex 52, individual reports from 29 long-term measured GSHP case studies in seven countries have been compiled. The GSHP systems have a range of applications and features. A majority of the GSHP systems use boreholes in the ground as the heat source and sink. Five of the GSHP systems use groundwater as the source for heating and cooling and four of the GSHP systems use energy piles, of which one combines energy piles with boreholes. The locations of the monitoring projects are shown in Figure 1 and the case study reports are available for download on the Annex 52 website:

<https://heatpumpingtechnologies.org/annex52/documents/>

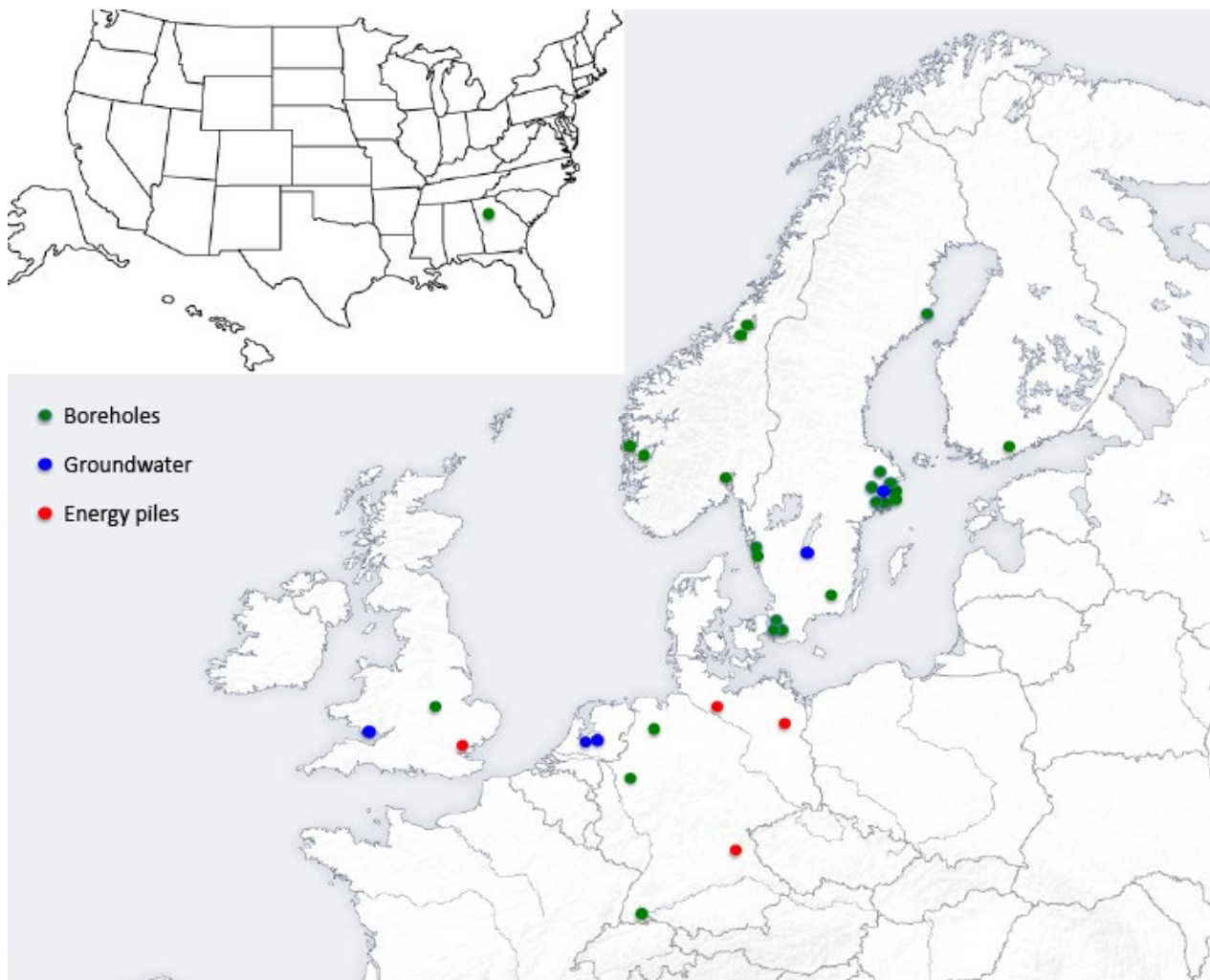


Figure 1: Monitored GSHP systems in the IEA HPT Annex 52 international collaboration project 2018-2021.

3. PERFORMANCE ANALYSIS

The overall performance of any GSHP system is affected by the performance of the source side ground circuit and the heat pump (HP) unit performance, as well as the load side circuit performance. This also includes supplementary heating and cooling. The experts within Annex 52 have identified performance indicators that will allow evaluation on all three levels – source side, heat pump unit and load side. These performance indicators can be used for commissioning, fault detection, system optimization and future system development, and will help answer a wide range of questions from interested parties.

3.1 System boundaries

When calculating a performance factor in a GSHP system, it is important to clearly define its boundaries. System boundaries may, e.g., be drawn around the ground heat exchanger circuit, around the heat pump itself, around the heat pump and ground circuit together, or around the entire system including the distribution pumps and fans. The performance will differ depending on how the boundaries are defined. In the literature, there is little consistency in the use of system boundaries. In many cases the system

boundaries are not clearly defined at all. Therefore one of the first tasks within Annex 52 was to harmonize system boundary definitions and identify and recommend performance indicators that will allow evaluation at multiple clearly stated system boundaries.

The starting point for this work was the SEPEMO system boundary schema (Nordman 2012), although the SEPEMO system boundary schema has limitations when accounting for the complexity of larger GSHP systems. Spitler and Gehlin (2019) found five other published system boundary schemas apart from the SEPEMO schema. Three of these schemas, by Winiger et al (2013), VDI (2016) and Koenigsdorff (2011), included a system boundary for the ground loop itself. Based on ideas from all six boundary schemas, a new system boundary schema consisting of six defined boundaries and an indicator for use of supplemental heating or cooling was defined within Annex 52 (Gehlin and Spitler 2021). The Annex 52 boundary schema is mostly based on the SEPEMO schema but is revised and extended, such that every SEPEMO boundary matches one of the Annex 52 boundaries, but there is also a system boundary for the ground heat exchanger circuit (boundary 0), and another that helps identifying the effect on the performance by buffer

tanks (boundary 3). Boundary 1 includes only the heat pump unit and the electricity used for the compressor. In practice it is often not feasible to measure system boundary 1 without also including electricity for parasitic losses within the heat pump, and internal circulating pumps and fans, where present. System

boundary 5 includes the entire GSHP system. The Annex 52 system boundary schema was implemented on all the Annex 52 monitoring projects. However, not all projects measured at every system boundary.

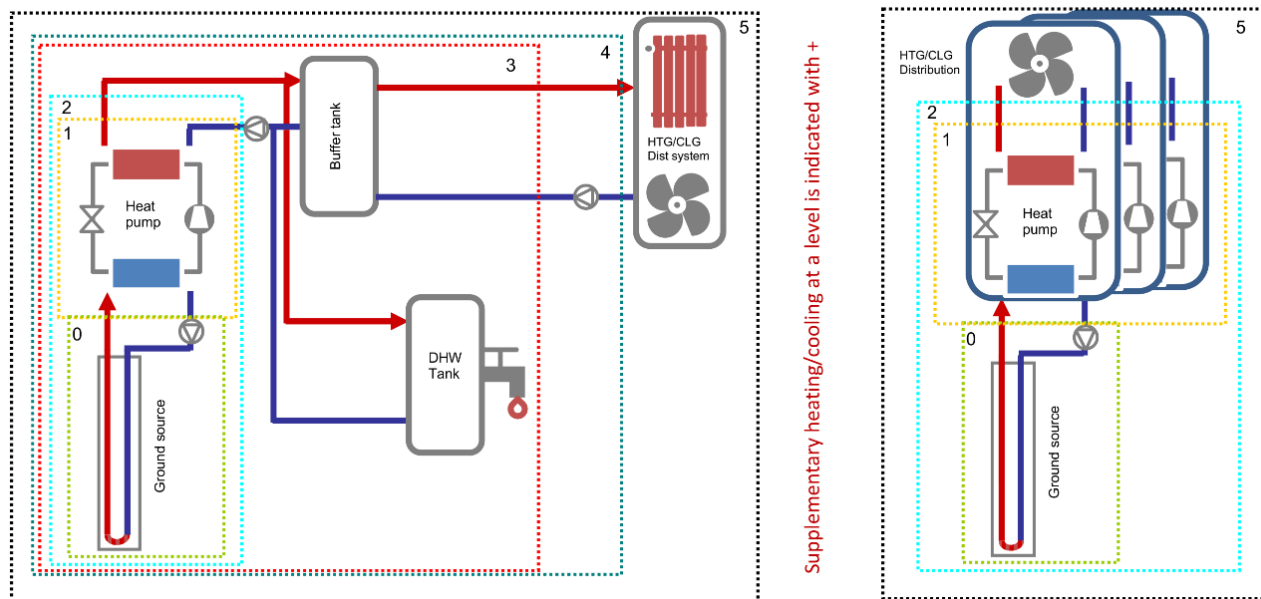


Figure 2: The Annex 52 system boundary schema applied for a centralized (left) and a distributed (right) GSHP system. Supplementary heating/cooling at a boundary level is indicated with +. (Gehlin and Spittler 2021)

3.2 Key performance indicators

The Annex 52 experts' group has identified a number of key performance indicators (KPIs) that can be used to characterize performance of GSHP systems at various system boundaries such as KPIs for the ground source, for the system components, and for the overall GSHP system level (Gehlin et al. 2022). In addition, some KPIs for the overall building level have also been defined to better understand the loads on the GSHP system. They may be useful for analyzing a building's characteristics and identify potential improvements in operation strategies.

For heat pump systems in general, system coefficients of performance (COP), energy efficiency ratios (EER) and seasonal performance factors (SPF) with various boundaries are often used. These indicators have the advantage of being able to focus solely on the actual system performance without comingling the effects of the building envelope and usage. The heat pump industry commonly uses the terms COP, SCOP, EER and SEER to refer to key performance indicators that are calculated based on physical testing of a heat pump unit under one or more conditions in a laboratory, and often have implications for codes and regulations. The term "performance factor" is used more widely when referring to field measurements.

For field measurements, Annex 52 promotes using "performance factor" with an indicator of the time period (seasonal, monthly, weekly, daily, or binned –

SPF, MPF, WPF, DPF, BPF) with subscripts that correspond to the defined boundary conditions, e.g. H1 for heating at boundary level 1, C2 for cooling at boundary level 2 and HC4 for combined heating and cooling at boundary level 4.

Apart from performance factors (PFs) at system boundary 0, other useful KPIs for analyzing the performance on the ground source circuit system boundary level (level 0 in the Annex 52 system boundary schema) are e.g. annual heat extraction rate, specific heat extraction rate, and the balance or imbalance between extracted and injected energy. For open loop systems various clogging indicators are useful to detect clogging at an early stage so that measures can be taken before it is too late.

Not all of the KPIs that have been identified within Annex 52 have been used in the monitoring projects, as not all indicators are relevant to every GSHP system. Financial indicators are not within the Annex 52 scope, but several of the performance indicators identified and recommended by Annex 52 provide the material for financial indicators and evaluation.

4. RESULTS

Numerous designs for ground heat exchangers have been proposed, going well beyond a single U-tube. Double U-tubes, triple U-tubes, co-axial heat exchangers, helical piping, arrangements with a single pipe in one direction and six or more tubes in the other

direction have all been proposed and installed. A common metric has been the borehole thermal resistance – the lower the value, the better. However, as with other heat exchangers, it is quite possible to improve the heat transfer performance at the expense of increasing the pumping power. In our opinion, another metric would be useful – one that combines the thermal performance with the hydraulic performance.

The performance factor for boundary 0 of the Annex 52 boundary schema is one such metric. It gives the ratio of heating delivered or cooling delivered, or heating + cooling delivered, to pumping energy for the ground heat exchanger. It also necessarily includes the effects of pressure losses in the heat pump and any above-ground piping between the ground heat exchanger and the heat pump.

The ASHRAE Headquarters ground-source heat pump system in Atlanta has been the subject of extensive analysis (Southard, et al. 2014a, 2014b; Spitler, et al. 2017, 2021). The GSHP system is a distributed system with 14 water-to-air heat pumps distributed around the building, with total nominal cooling capacity of 119 kW (31.5 tons). The pumping system utilizes a central circulating pump combined with individual solenoid valves controlling the flow to each heat pump – the valve is open when the heat pump is providing heating or cooling and shut otherwise. The pump speed is controlled to maintain a constant differential pressure across the heat pumps. This has the effect of keeping flow rate to each heat pump approximately constant when the heat pump is on. The total system flow may vary significantly as the number of heat pumps on increases and decreases. When the system was installed in 2008, the differential pressure setpoint was set to 138 kPa. On April 20, 2012, an astute visiting engineer noticed that the setpoint was higher than desirable, and it was reset to 55 kPa.

The GSHP system provides both heating and cooling, and during the Atlanta winter months, may frequently provide both in the same week. Therefore, the performance of the system was analyzed for heating and cooling combined. Weekly performance factors (WPF) have been computed for boundary 0 and boundary 5. Figure 3 shows results for WPFHC0. As can be seen, the setpoint change significantly increased the performance of the source-side portion of the system. For a given amount of heating and cooling provided, the pumping energy was substantially increased after the differential pressure setpoint was reduced.

Figure 4 shows the results for WPFHC5, which includes the entire system. Here the change is not as

obvious, though a shift upward can be seen from the winter of 2011-2012 to the winter of 2012-2013. The effect of changing the differential pressure setpoint on the overall system is not as marked for several reasons, primarily because the total heating and cooling and total system energy are quite a bit higher than the heat extraction and heat rejection and pumping energy. Secondly, as discussed in Spitler, et al. (2017) there is some tradeoff between pumping energy and heat pump energy. Decreasing the differential pressure setpoint reduced the flows in every heat pump. While this saves pumping energy, it also increases energy used by the heat pump.

5. ANNEX 52 OUTCOMES

The overall outcomes from Annex 52 include a new heat pump system boundary schema, an annotated bibliography with published long-term performance monitoring of larger GSHP systems, three guideline documents, and 27 case study reports containing 29 monitoring projects in Europe and the USA. These publications comprise more than 1000 pages in total and are published on the Annex 52 webpage <https://heatpumpingtechnologies.org/annex52/documents/>. In addition, three sets of open-source measurement data from two GSHP systems have been made available.

5.1 Bibliography

The annotated bibliography (Gehlin and Spitler 2022) compiled within Annex 52 includes a total of 82 publications. It gives an overview of published literature reporting on long-term measured (at least one full season of measured data) performance values (SPF, COP) for larger GSHP systems. The document is divided into two parts of which the first part includes 64 publications from 2002 to 2021, reporting on long-term performance monitoring of larger GSHP systems that provide measured seasonal performance factors. The second part contains an additional 18 publications from 1995 to 2020 that report on larger GSHP systems that present measured performance other than SPF.

A key finding of the bibliographic research was that there is a lack of consistency both on how to measure the performance and on how to report the results from such measurements. It also showed that performance factors are rarely reported with estimated uncertainties. Only a handful of publications include uncertainty analyses.

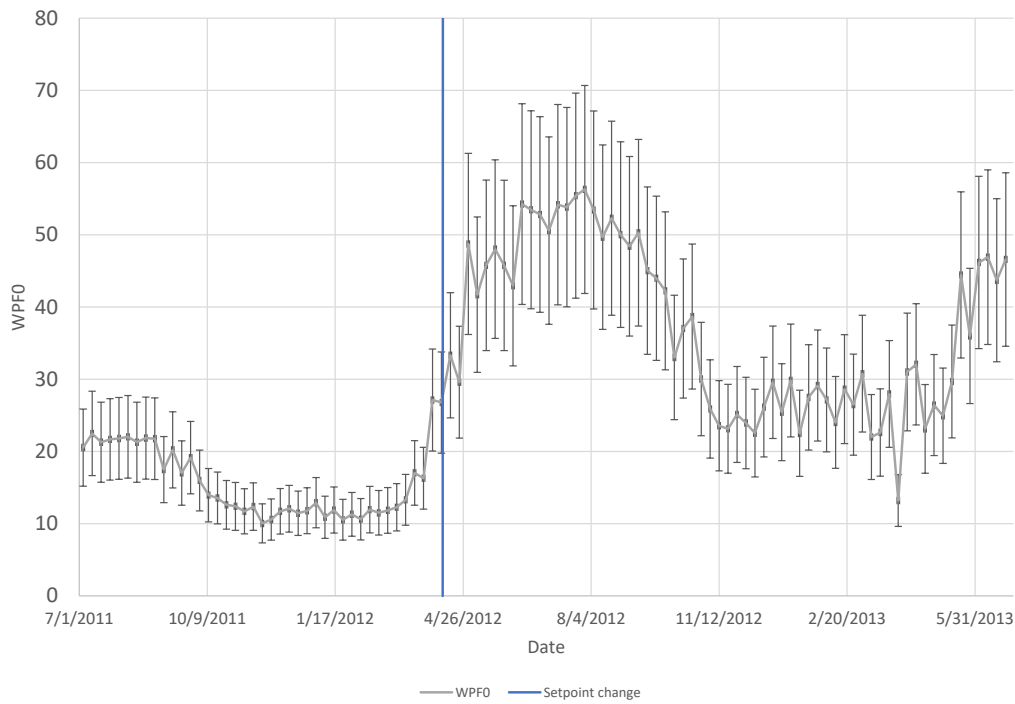


Figure 3: Weekly boundary 0 performance factors for the ASHRAE Headquarters ground-source heat pump system

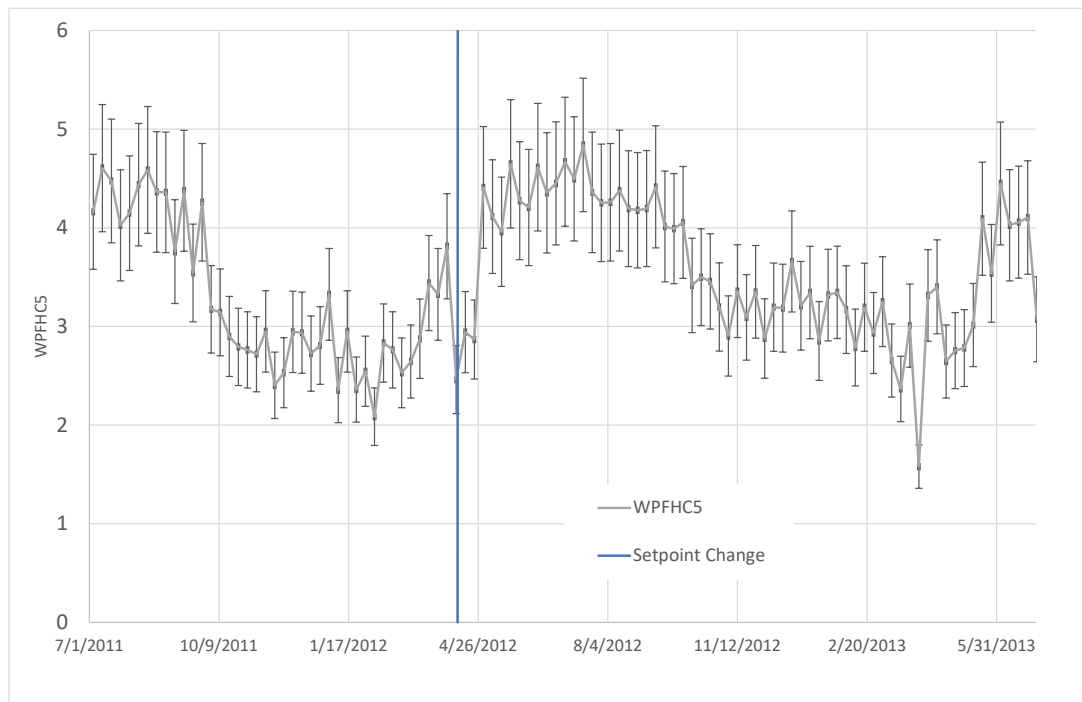


Figure 4: Weekly boundary 5 performance factors for the ASHRAE Headquarters ground-source heat pump system.

5.3 Instrumentation guideline

The Annex 52 instrumentation guideline (Davis et al. 2021) focuses on the instrumentation needed to measure the performance of a GSHP system, rather than the methods of analysis, and includes a wide range of potential measurements that can be used for a variety of purposes. In some cases, there is opportunity to

design a monitoring and verification program at the beginning of a project and specify the types, accuracies, and placement of sensors as well as the characteristics of the sensor network. In other cases, the analyst may be using existing sensors that are part of an existing building management system. The guideline document aims to inform practitioners about the wide range of possibilities that may be encountered but does not

prescribe the methods of instrumentation or data analysis, which will vary from site to site and depend on many factors. It presents an overview of instrumentation that is typically required to measure the long-term performance of GSHP systems. GSHP performance studies can be conducted to meet a variety of monitoring and verification (M&V) objectives and they also provide data that can be used to improve system performance. The guideline also provides additional information regarding the use of the heat meters and distributed temperature sensing in GSHP studies. Finally, the challenges of data management are discussed as well as some methods to address these challenges.

5.4 Guide to KPI

The KPI guideline document (Gehlin et al. 2022) gives directions on why and how to measure, analyze and present long-term (here defined as at least one full season) performance data with emphasis on heat pump and system performance. The report is based on the results from the many monitoring projects carried out within Annex 52 and provides guidance on system boundaries, key metrics, and examples from some of the Annex 52 case studies. The work summarized in the report is a step towards standardized methods and analyses that will support widespread performance monitoring of GSHP systems. Combined with the Instrumentation guideline (Davis et al 2021), the KPI guideline offers help to building owners in setting up cost-effective monitoring programs and instrumentation for their GSHP systems.

4. CONCLUSIONS

IEA HPT Annex 52 has contributed to the field's body of knowledge regarding measurement of ground-source heat pump performance through a collaborative effort of researchers from seven participating countries. The 29 case studies measured field performance of large GSHP systems, providing both benchmarking data and experience that was utilized in developing new guidelines for instrumentation, uncertainty analysis, and key performance indicators.

We anticipate that providing the guidelines will help lead to lower costs for monitoring programs, as properly designed instrumentation installed concurrently with the system installation will cost less than retrofitting the system and reduce the engineering time needed to overcome insufficiently accurate sensors and inadequate sensor placement.

In this paper, we focused on a system performance factor (boundary level 0) that characterizes the performance of the ground heat exchanger and source-side pumping system. Future use of this analysis can help ensure that GSHP systems provide the high level of performance expected. It can also be used to help ensure that systems that use "free cooling" are actually providing significant benefits compared to systems utilizing heat pumps.

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