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Half-term Results from IEA HPT Annex 52 - Long-term Performance Monitoring of Large GSHP Systems

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Abstract

IEA HPT Annex 52, *Long-term performance measurement of GSHP systems serving commercial, institutional and multi-family buildings*, started in January 2018 and will close in December 2021. Within the annex, a large number of larger ground source heat pump (GSHP) systems in seven countries are monitored and analyzed from a long-term performance perspective. By the end of 2019, 40 GSHP performance-monitoring case studies, located in Sweden, the Netherlands, the UK, Finland, Germany, Norway and the USA, form part of the Annex 52 work. These case studies cover a range of building types, system applications and ground sources. Annex 52 offers unique experience and information on GSHP system performance, which will result in guidance on instrumentation, monitoring, uncertainty analysis, data analytics, performance analysis and suitable performance indices based on international experience. This paper gives an overview of Annex 52, including the active monitoring projects and the work and findings so far.

Keywords: Ground source; GSHP; performance; monitoring; HPT Annex 52

1. Introduction

The four-year international collaboration project IEA HPT Annex 52, *Long-term performance measurement of GSHP systems for commercial, institutional and multi-family buildings*, has now reached its midway point. As of the end of 2019, seven countries are participating in this annex (Sweden, the USA, Finland, Norway, Germany, the UK and the Netherlands). The aim of this IEA Annex is to monitor and analyze a large number of ground source heat pump systems in several countries from a long-term performance perspective. The emphasis is on heat pump and system performance, e.g. determining coefficients of performance, seasonal performance factors and other system efficiency indices. The results and experience from the many monitoring projects will be used in three annex subtasks. Within the first subtask, an annotated bibliography of previously published long-term monitoring projects reported will be compiled, together with a case study report summarizing all the included Annex 52 monitoring projects. The second and third subtasks will provide guideline documents on instrumentation, monitoring, analysis and key metrics for long-term performance of large ground source heat pump (GSHP) systems.

It is a well-known fact that many building heating and cooling systems consume excess energy due to problems that are only discovered after months or years, and that design decisions and control settings can have significant deleterious impacts on energy efficiency, and yet are poorly understood. Unless performance measurements are made, such problems may never be detected. Table 1 lists possible questions that may be answered by performance monitoring. This Annex is taking steps to standardize methods and analyses that will support widespread performance monitoring of ground-source heat pump systems.

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Table 1: Possible questions to be answered by performance monitoring

Possible users	Questions to be answered
Prospective building owners	Is a GSHP system worth the extra investment?
Building owners	Is my system saving me the money that I expected?
Building owners	How does my system compare to other systems in the area serving similar buildings?
Building owners	How well does my system meet environmental criteria and building certification requirements?
Code-writing and regulatory bodies	How can we make informed decisions for energy policy, codes, and regulations?
Consulting (HVAC design) engineers	Do the systems I designed work as well as I expected? What should I do differently next time?
Consulting (HVAC design) engineers	How have other GSHP systems for similar applications in my area worked?
Building maintenance staff	Does my system need attention? Are there any failing components? Has the performance increased or decreased since last year? Is it likely to fail in the coming year?
Building energy managers	Is there room for further improvement in the system, or do we need to address other areas?
Controls engineers	How can setpoints be optimized? What are optimal setpoint values?
Commissioning agents	How does the system work compare to the intended design? Is the system constructed according to design documents?
Equipment manufacturers	How well do my products perform in the field? What market opportunities are there for new products and new features on existing projects?
Environmental Certification and Building Performance Certification Authorities	How can certification programs reward real energy efficient systems and not just planned efficiency or low building energy consumption, which may be due to low occupancy?
Handbook authors	What are best practices leading to highly efficient systems?
Researchers	How can simulation models be validated?

1.1. Performance indicators

The over-all performance of a GSHP system is affected by the performance of the source side ground circuit, as well as the heat pump (HP) unit performance and the load side circuit performance, including supplementary heating and cooling. Within Annex 52 we aim to identify and recommend performance indicators that will allow evaluation on all three levels, from a commissioning point of view as well as for fault detection, system optimization and future system development. Table 2 gives an overview of GSHP system performance indicators at various system levels.

A commonly used performance indicator for building heating and cooling systems is energy use intensity (EUI), typically expressed as annual energy usage of the building per unit area, e.g. kWh/m^2. EUI does not differentiate between the effects of the building envelope, its usage, and the performance of the heating and cooling system. Hence it gives little information about GSHP system performance. For GSHP systems, system coefficients of performance (COP) and seasonal performance factors (SPF) with various boundaries have occasionally been reported in the literature. Such measurements, whether termed COP or SPF, have the advantage of being able to focus solely on the actual system performance without comingling the effects of the building envelope and usage. Within the heat pump industry, certain terms (COP, SCOP, EER, SEER) are commonly used to refer to indices that are calculated based on physical testing of a heat pump unit under one or more conditions in a laboratory. Although these indices often have implications for codes and regulations, some researchers [1-3] have used “COP” or “SCOP” to refer to field measurements. The term “performance factor” is used more widely when referring to field measurements, but it has also been used [4] to refer to calculated values based on testing of heat pumps under multiple conditions in a laboratory. SPF (Seasonal Performance Factor) has also been used to refer to periods shorter than a year, e.g. Wemhoener et al. [5] present a graph with monthly SPF. Given the confusing situation, we plan to use the term “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 boundary conditions, e.g. H1, C4.

Table 2: GSHP system performance indicator matrix

	Is it as designed? (Commissioning)	Does it work well? (Fault detection)	Could it work better? (Optimization)	Could future systems work better?
Ground source	Do measured ground heat exchanger loads, flow rates and temperatures match design values?	What are the measured ground circuit (level 0) performance factors over seasons, months, days? Temperatures and pressure drop?	Could ground circuit pumps and pump control strategies be adjusted? Are there delay times in on-off mode? Are set-points optimal?	Can borehole thermal resistance be decreased? Could better hydraulic design and lower pressure drop be obtained?
Heat pump unit	Do measured HP entering fluid temperatures and flow rates, match design values?	What are the measured HP unit (level 1) performance factors over seasons, months, days? System Efficiency Index (SEI)? Temperatures and pressure drop?	Could HP unit controls be changed (e.g. control curves and set points) Could the HP be changed?	Could sizing be better? Could internal control be improved?
System level	Do measured temperatures, flow rates, energy signatures, seasonal heating and cooling loads and supplemental heating and cooling match design values?	What are the measured system (level 2-5) performance factors over seasons, months, days? Temperatures and pressure drop? Simultaneous heating and cooling?	Are operation schedules and control set-points for supplementary heating and cooling optimal?	Could better hydraulic design and lower pressure drop be obtained? Could components be improved?

2. Annex 52 achievements

In its first two years, Annex 52 has gathered more than 60 international experts from research institutions and industry at four international experts' meetings and a number of national workshops. The focus has been on selecting and setting up GSHP monitoring case studies in all participating countries and surveying previously published large-scale GSHP long-term performance studies and performance indicators. Based on this work, guideline documents and recommendations are under way. A summary of the Annex 52 outcomes so far follows.

2.1. Bibliography

In partial fulfillment of Annex 52 subtask 1, the participants have compiled an annotated bibliography containing 65 publications describing 55 buildings where long-term performance monitoring of larger GSHP systems has been performed and that contain some form of SPF measurement. A further 18 references describe monitoring of larger GSHP systems that do not go as far as determining any SPF. Spitler and Gehlin [6] present a comprehensive review of this performance measurement literature for large GSHP systems. The authors conclude that nomenclature for performance indicators used by different authors is inconsistent, reflecting a lack of consensus on how to evaluate, express and present performance for complex large-scale GSHP systems. Another conclusion is that existing performance data is far too limited to be useful in setting performance expectations.

2.2. System boundary schema

As a starting point for Annex 52 the system boundary schema developed within the EU project SEPEMO [7] has been used for calculation of COP and SPF. The SEPEMO schema is used for SPF calculations of ground, air and water source heat pumps in the EU renewable energy directive. However, several other similar schemas have been published in the literature. Spitler and Gehlin [6] identified five other system boundary schemas different from the SEPEMO schema. For the most part, these schemas are aimed at small monovalent or bivalent heat pump systems and have limitations when accounting for the complexity of larger GHSP systems used in commercial, institutional and multi-family residential buildings. Though performance evaluation for most of the case studies included in Annex 52 is still in the beginning stages, it is evident that the SEPEMO boundary schema used for SPF calculation is insufficient for covering the complex nature of large-scale GSHP systems.

Therefore, as part of subtask 3 the Annex 52 group has proposed a new system boundary schema, consisting of six defined boundaries and an indicator for use of supplemental heating or cooling (Figure 1). This system boundary schema is better suited for large and complex GSHP systems of the kind that are the focus of Annex 52. The system boundary schema may be used for seasonal performance factors (SPF), shorter time intervals, e.g. daily, monthly (DPF, MPF), or binned performance factors (BPF). The system boundary schema is an extension of the SEPEMO schema, such that every SEPEMO boundary matches one of the Annex 52 boundaries (Table 3). The proposed schema is now being tested on the 40 included case studies within Annex 52.

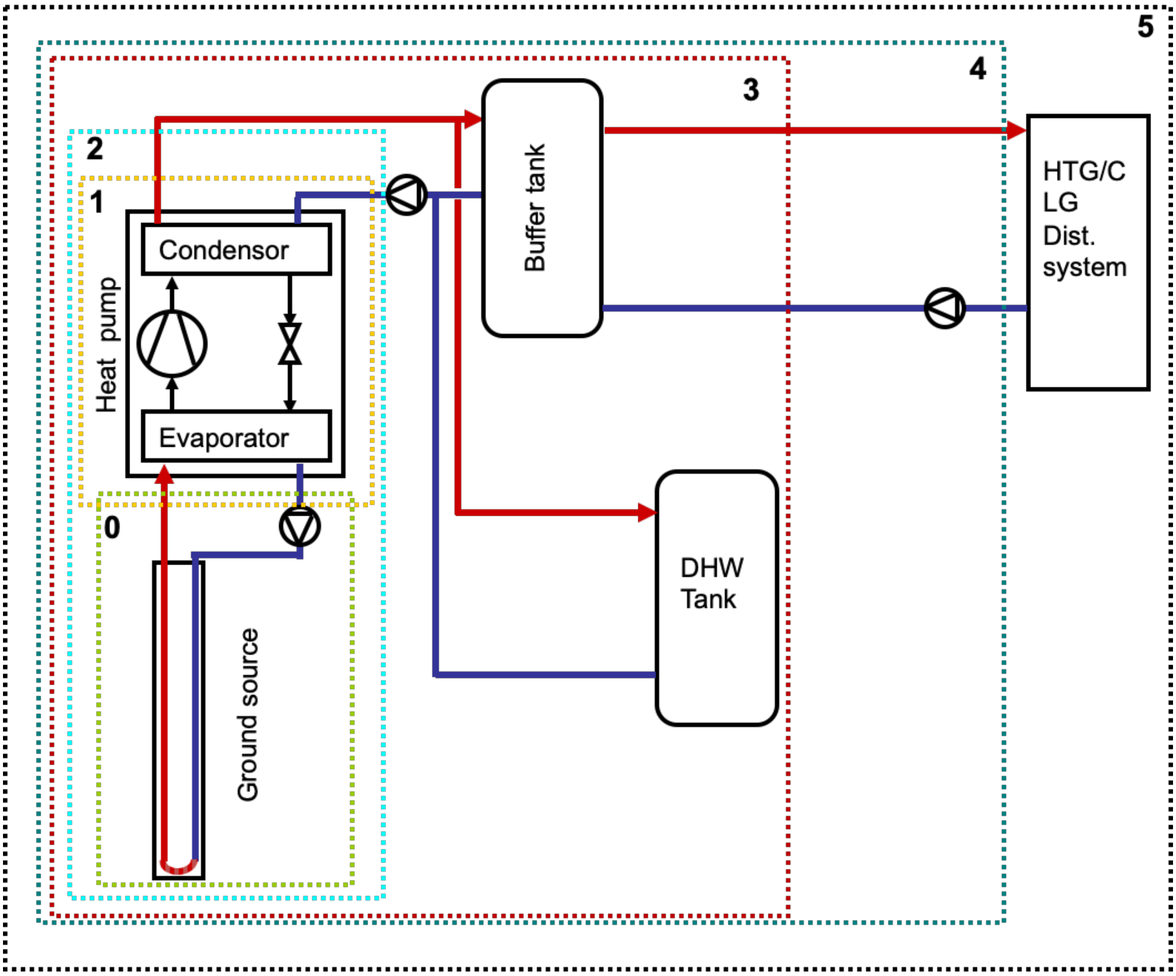

Fig. 1. Proposed Annex 52 system boundary schema. Auxiliary heating and cooling could be added at any boundary level, which will then be indicated with a "+" superscript.

Table 3: System boundary schema comparison of the SEPEMO scheme and the proposed Annex 52 schema for SPF and COP. (Mapping corresponds with having auxiliary heating (H) or cooling (C) only at the same levels as SEPEMO. For the proposed schema, the "+" superscript indicates auxiliary heating/cooling within the boundary).

Boundary description	Boundary levels											
	0	0+	1	1+	2	2+	3	3+	4	4+	5	5+
Ground Source (CP + GHE)	X	X			X	X	X	X	X	X	X	X
Heat pump unit including internal energy use, excluding internal CP			X	X	X	X	X	X	X	X	X	X
Buffer tank (including CPs between HP and BT)							X	X	X	X	X	X
CP on load-side (between BT & building H/C distr. system)									X	X	X	X
Building H/C distribution system											X	X
Auxiliary heating or cooling		X		X		X		X		X		X
Equivalent in the SEPEMO boundary schema			H1/C1		H2/C2	H3					C3	H4/C4

2.3. Case studies

As part of Annex 52 subtask 1, 40 GSHP monitoring case studies, covering a range of applications, located in seven countries, are included in the annex work. Locations and types of ground sources for the 40 case studies are summarized in Figure 2 and Table 4. These case studies, in various stages of completion, will be reported with consistently defined performance indicators in a comprehensive case study report at the closing of Annex 52. Results from several of the Annex 52 case studies have already been published in reports, conference papers and journal papers. These are indicated with an asterisk in Table 4.

Naicker and Rees [8-9] present seasonal system performance factors for the GSHP system serving the Hugh Aston building in Leicester in the UK. Seasonal performance factors are presented for SEPEMO levels C1 and H1, and combined cooling and heating SPF, referred to as SPF1, SPF2, and SPF4, are also defined corresponding to SEPEMO levels H1, H2 and H4. The authors show that cycling losses increase with decreasing cycle time, and that SPF2 and SPF4 are affected by the pumping controls that start the circulating pumps three minutes before the compressors. Several approaches to improving the system performance are identified.

Spitler and Gehlin [6] analyze one year of monitoring data for the mixed-use commercial GSHP system for the student union building Studenthuset at the university of Stockholm in Sweden. SPF values for SEPEMO boundaries H2, H3 and C2 are calculated. The authors show that the system provides space heating consistent with the design values, and that the cooling provided is about four times higher than anticipated in the design. Measured COPs are more affected by the amount of heating and cooling provided than by the entering fluid temperature to the heat pumps. Heating COPs are higher at lower entering fluid temperatures, which correspond to higher run-time fractions for equipment and less influence of “parasitic” loads such as pumps and unit control boards. The Legionella protection system and domestic hot water (DHW) recirculation system run all the time, causing the COP to approach 1 at times in the summer. In addition, the minimum flow rate set point in the borehole circuit leads to excess flow and excess energy consumption by the circulating pump.

The journal papers by Naicker and Rees [8-9] and Spitler and Gehlin [6] provide two sets of high-quality open access measurement data, which may be used by researchers and developers in their future work. Providing at least one set of open access reference monitoring data for a large commercial GSHP system has been one of the important goals of HPT Annex 52.

Results from long-term performance monitoring of two distributed heat pump systems at the ASHRAE Headquarters building in Atlanta in the USA were published by Southard et al. [10, 2] and Spitler et al. [11]. An air-source variable-refrigerant flow heat pump system and a ground-source heat pump system were analyzed and seasonal heating and cooling system coefficients of performance were calculated for the two systems. Because the distributed heat pumps delivered heating and cooling with fans integrated in the heat pump units, and the electrical energy was measured for all heat pumps and the source-side circulating pump together, the coefficients of performance correspond to SEPEMO levels H4 and C4.

The industrial high-temperature borehole storage in Emmaboda in Sweden was operated without heat pumps over several years [12-13]. In 2018 heat pumps were installed. This will improve the possibilities to cool industrial processes and provide improved thermal comfort in the facility. System performance before and after heat pump installation will now be compared.

Boon et al. [14] describe a retrofitted groundwater loop heat pump system at Grangetown nursery school in Cardiff, UK, and its three years of field monitoring. Seasonal performance factors corresponding to SEPEMO level H4 were calculated to be 4.5 over the measurement period.

A first performance evaluation of the early operation of the Rosenborg groundwater heat pump system in Stockholm, mainly focused on the ground source performance, is presented by Abuasbeh and Acuña [15].

Two GSHP systems for multi-family buildings in Stockholm were analysed by Börjesson [16]. One of the buildings was built in 1939 and has been retrofitted with a GSHP system in two steps in 1970 and 2011. This building has supplementary heating with district heating. The other building and its GSHP system were built in 2011 and has supplementary heating from electric heating. Seasonal performance factors over 8 years of operation, corresponding to SEPEMO level H2 and H3 were calculated for the first building and level H2, H3 and H4 were calculated for the second building.

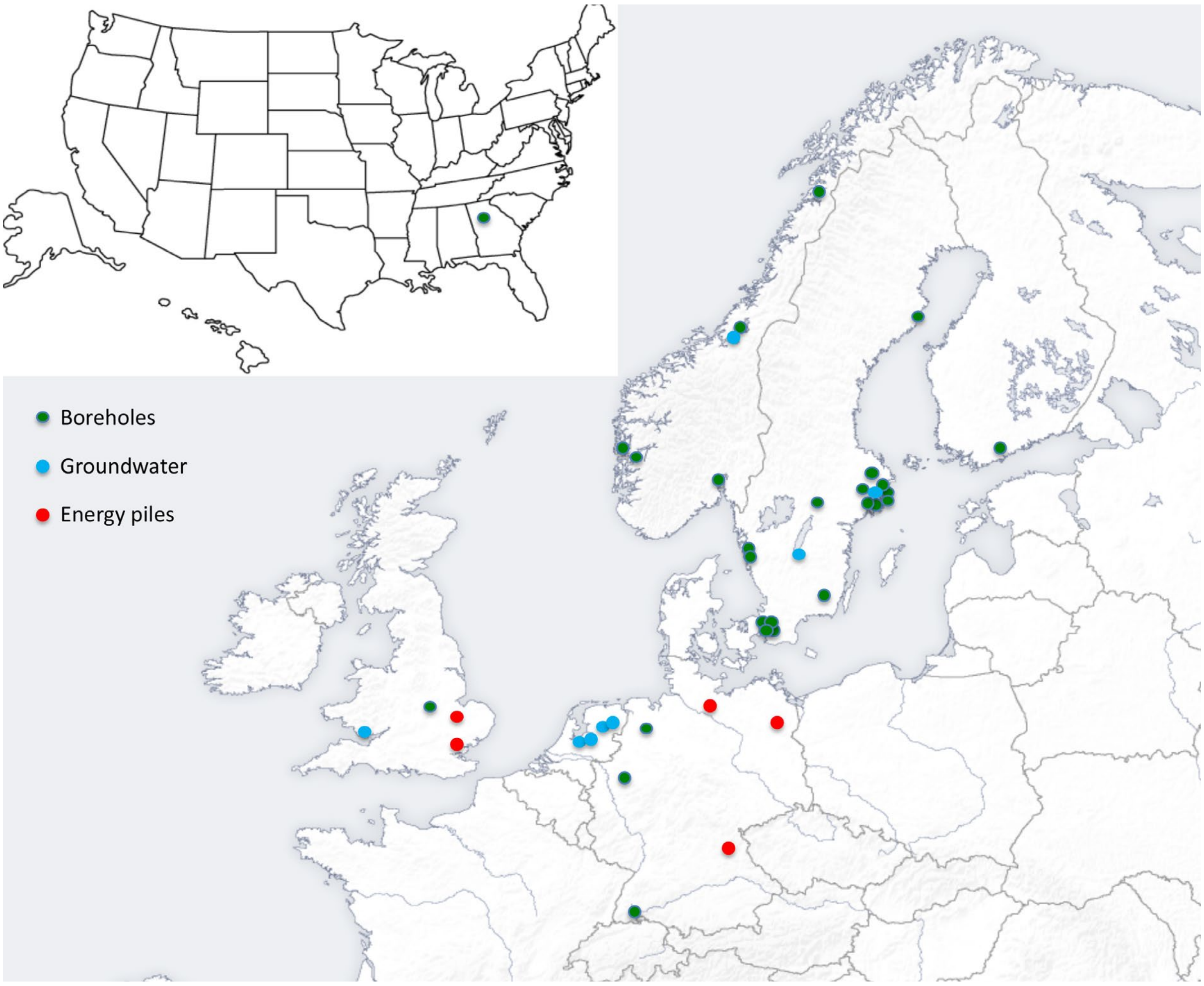

Fig. 2. GSHP case studies included in IEA HPT Annex 52 by the end of 2019.

Table 4: The GSHP monitoring projects included in IEA HPT Annex 52 by the end of 2019. *) Publication available.

#	Country	Location	Building name	Building type	Ground source
1	Finland	Espoo	Aalto University	University	Boreholes
2	Germany	Vechta	AOV	Office	Boreholes
3	Germany	Geisenkirchen	GEW	Office	Boreholes
4	Germany	Konstanz	KON	Residential	Boreholes
5	Germany	Berlin	EFB	Office	Energy Piles
6	Germany	Lüneburg	VGH	Office	Energy Piles
7	Germany	Neumarkt	WGG	School	Energy Piles
8	Netherlands	Utrecht	SKU OVT	Office/train station	Aquifer
9	Netherlands	Drente	Provinciehuis	Office	Aquifer
10	Netherlands	Amsterdam	DeLaMar Theatre	Theatre	Aquifer
11	Netherlands	Meppel	The Schiphorst	Care home	Aquifer
12	Norway	Bergen	Scandic Flesland	Conference hotel	Boreholes
13	Norway	Drammen	Fjell skole	School	High temperature Boreholes
14	Norway	Saltdal	Vensmoen Eiendom	Assembly building	Boreholes
15	Norway	Trondheim	Otte Nielsens vei 12E	Office	Boreholes
16	Norway	Melhus	Lena Terasse	Residential	Aquifer
17	Norway	Bergen	Sweco office building	Office	Boreholes
18*	Sweden	Stockholm	Studenthuset	Office	Boreholes
19*	Sweden	Emmaboda	Xylem	Industry	High temperature Boreholes
20	Sweden	Lund	Traktorn	Residential	Boreholes + District heating
21	Sweden	Lund	Briljanten	Residential	Boreholes + District heating
22	Sweden	Jönköping	Domstolen	Office	Aquifer
23	Sweden	Gothenburg	Backadalen	Residential	Boreholes + District heating
24	Sweden	Uppsala	IKEA	Warehouse	Boreholes
25	Sweden	Umeå	NUS	Hospital campus	Boreholes in thermal grid
26	Sweden	Stockholm	KTH Rocks	Residential	Boreholes
27	Sweden	Stockholm	NPQ	University campus	Boreholes in thermal grid
28*	Sweden	Stockholm	Rosenborg	Office	Aquifer
29	Sweden	Malmö	Polishuset	Office	DGC Boreholes
30	Sweden	Malmö	Klipporna	Office	Boreholes
31	Sweden	Gothenburg	Frölunda Club	Club house	Boreholes
32	Sweden	Stockholm	Lindhagen	Office	DGC Boreholes
33	Sweden	Stockholm	Beckomberga	Residential	Boreholes + Sewage
34*	Sweden	Stockholm	011-Stockholm	Residential	Boreholes + District heating
35*	Sweden	Stockholm	249-Stockholm	Residential	Boreholes + Electric heating
36*	UK	Leicester	Hugh Aston Building	University	Boreholes
37*	UK	Cardiff	Grangetown	Nursery school	Aquifer
38	UK	London	The Crystal	Office	Boreholes/Energy piles
39	UK	Cambridge	22 Station Road	Office	Energy Piles
40*	USA	Atlanta	ASHRAE HQ	Office	Boreholes

2.4. On-going guideline preparation

Within the Annex 52 subtask 2, instrumentation and measurement guidelines are currently in preparation. The instrumentation guideline document will cover GSHP system-related instrumentation hardware and its installation and associated error and uncertainty, as well as data management with recommendations on measurement intervals and data storage. A draft document has been compiled and discussed; an updated version will be presented in the spring of 2020. Another related useful tool for quantitative evaluation of monitoring data from GSHP systems is a guide to uncertainty analysis that has been prepared as an aid to the Annex 52 case studies and future performance monitoring studies. This document will be an integrated part of the final instrumentation guideline.

In parallel with the instrumentation guideline, there is on-going work on defining recommended key performance indicators for various system boundaries and performance objectives (Tables 1 and 2). These recommended performance indicators will affect the instrumentation guideline recommendations on instrumentation points.

3. Conclusions

Annex 52, *Long-term performance measurement of GSHP systems for commercial, institutional and multi-family buildings,* aims to provide tools to improve the state of the art, based on wide international experience from 40 case studies evaluated as part of the annex. These tools include an improved boundary schema with complementary performance indicators, guidelines on instrumentation and monitoring, guidelines on analysis and key metrics, a thorough bibliography and a unique case study report with long-term performance evaluation of 40 GSHP systems worldwide, using a harmonized evaluation scheme. The results from Annex 52 will contribute significantly to harmonization and system development of such tools. With these new tools, we hope to prepare the way for widespread long-term performance monitoring to become a useful tool for a variety of end users in the GSHP market, such as the audiences listed in Table 1.

At half-term, Annex 52 has already fulfilled two of its goals – the annotated bibliography of previously published large-scale GSHP performance measurements, and two sets of open access reference data. Updates on the Annex 52 work and results are continuously posted on the Annex web site [17].

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References

[1] Zhai, X. Q. and Yang, Y.: Experience on the application of a ground source heat pump system in an archives building. Energy and Buildings 43(11): 3263-3270. (2011).
[2] Southard, L.E., Liu, X., Spitler, J. D.: Performance of HVAC Systems at ASHRAE HQ, Part 2. ASHRAE Journal, December 2014, 12-23. (2014b).
[3] Liu, X., Malhotra, M., Im, P.: Performance Analysis of Ground Source Heat Pump Demonstration Projects in the United States. Proceedings of the 12th IEA Heat Pump Conference, May 2017, Rotterdam, the Netherlands. (2017).
[4] IEA HPT TCP: Annex 39. A Common Method for Testing and Rating of Residential HP and AC Annual/Seasonal Performance. Final Report. HPT-AN39-1. (2016)
[5] Wemhoener, C., Hässig, W., Wyss, S., and Staubli, J.: Heat pump application in nearly zero energy buildings. Science and Technology for the Built Environment 23(4): 637-650. (2017).
[6] Spitler, J.D. and S.E.A. Gehlin.: Measured performance of a mixed-use commercial-building ground source heat pump system in Sweden. *Energies* 2019, **12**, 2020; doi:10.3390/en12102020. Open access at: https://www.mdpi.com/1996-1073/12/10/2020 (2019).
[7] Nordman, R.: Seasonal Performance factor and Monitoring for heat pump systems in the building sector, SEPEMO-Build, Final Report. Intelligent Energy Europe. (2012).
[8] Naicker, S. S. and S. J. Rees.: Performance Analysis of a Large Geothermal Heating and Cooling System. *Renewable Energy* **122**:429–42. https://doi.org/10.1016/j.renene.2018.01.099 (*Measurement data available as open access at* ***http://archive.researchdata.leeds.ac.uk/272/***). (2018).
[9] Naicker, S. S. and S. J. Rees.: Long-term high frequency monitoring of a large borehole heat exchanger array. *Renewable Energy,* **145**:1528-1542. https://doi.org/10.1016/j.renene.2019.07.008 (*Measurement data available as open access at* ***http://archive.researchdata.leeds.ac.uk/272/***). (2020).
[10] Southard, L.E., Liu, X., Spitler, J. D.: Performance of HVAC Systems at ASHRAE HQ, Part 1. ASHRAE Journal, September 2014, 14-24. (2014a).
[11] Spitler, J. D., Southard, L. E., Liu, X.: Ground-source and air-source heat pump system performance at the ASHRAE headquarters building. Proceedings of the 12th IEA Heat Pump Conference 2017, Rotterdam, The Netherlands, May 15-17, 2017. 12 pp. (2017).

[12] Nordell, B., Liuzzo Scorpo, A., Andersson, O., Rydell, L., Carlsson, B.: The HT BTES plant in Emmaboda. Operation and Experiences 2010-2015. Water Resources Engineering. Luleå University of Technology, Research Report. (2016).
[13] Andersson, O., Rydell, L.: The HT-BTES in Emmaboda, Sweden – Lessons learned and Further Actions. Enerstock 2018, Adana, Turkey, April 2018. (2018).
[14] Boon, D.P., Farr, G.J., Abesser, C., Patton, A.M., James, D.R., Schofield, D.I., Tucker, D.G.: Groundwater heat pump feasibility in shallow urban aquifers: Experience from Cardiff, UK. *Science of the Total Environment* **697** (2019) 133847. 11 pp. (2019).
[15] Abuasbeh, M., Acuña, J.: ATES System Monitoring Project, First Measurement and Performance Evaluation: case study in Sweden. IGSHPA Research Track 2018, Stockholm, Sweden, September 18th 2018. (2018).
[16] Börjesson, M.: Performance evaluation of ground source heat pump heating systems in Stockholm. Master Thesis, KTH The Royal institute of technology, Stockholm, Sweden. To be published in autumn 2019 at http://kth.diva-portal.org. (2019).
[17] IEA HPC.: Annex 52 - Long term performance measurement of GSHP Systems serving commercial, institutional and multi-family buildings. Retrieved Nov. 29, from https://heatpumpingtechnologies.org/annex52/ (2019).