Commissioning, Preventive Maintenance, and Troubleshooting Guide for Commercial Ground-Source Heat Pump Systems

This project was supported by ASHRAE and the Geothermal Heat Pump Consortium.

Cognizant Technical Committee: TC 6.8, Geothermal Energy Utilization.

This publication was prepared by
Caneta Research Inc., Mississauga, Ontario, and Sachs & Sachs, Inc., McLean, Virginia under ASHRAE Special Project 94.

Any updates/errata to this publication will be posted on the ASHRAE Web site at www.ashrae.org/publicationupdates.

SP-94

Commissioning, Preventive Maintenance, and Troubleshooting Guide for Commercial Ground-Source Heat Pump Systems

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ISBN 10: 1-931862-09-5
ISBN 13: 978-1-931862-09-7

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and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, N.E.
Atlanta, GA 30329
www.ashrae.org

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Printed in the United States of America

Cover design by Tracy Becker.

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Acknowledgments

The development of this commissioning, preventive maintenance, and troubleshooting guide for commercial and institutional building ground-source heat pump systems would not have been possible without the financial support of the sponsors, the Geothermal Heat Pump Consortium (GHPC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

The authors acknowledge the valuable review and comment received from members of the T.C. 6.8 Project Monitoring Subcommittee on an early version of the draft. These members include:

- David Dinse
- Gus Foster
- Steve Carlson
- Spencer Morash

The same draft was sent for external expert review. It was considered important to get this expert input on the document from experienced practitioners, to ensure the technical accuracy, relevance, and value of the resulting guide to the industry at large. Expert review was provided by:

- Robert Brown, ClimateMaster
- Robert Mancini, Mancini, Saldan & Associates
- Cedric S. Trueman, Trueman Engineering Services
- Kevin Rafferty, Geo-Heat Center

Robert Brown provided a manufacturer's perspective on the guide content. Robert Mancini provided an A/E perspective, having designed a very large number of commercial/institutional ground-source systems. Cedric S. Trueman was a member of the Guideline 1-1996 Project Committee, which drafted the *HVAC Commissioning Process* document, and provided valuable suggestions for the commissioning chapter. Kevin Rafferty reviewed and suggested revisions on sections dealing with groundwater systems throughout the guide.

The authors also wish to express their appreciation to the following companies who provided product information used in the development of Chapters 3 and 4 on maintenance and troubleshooting: Econar, WaterFurnace International, Performance Pipe, Trane, National Groundwater Association, J and P Engineers and Tracer Research Corporations.

Chapter 1
Introduction

BACKGROUND

Ground-source heat pump systems (GSHPs), also known as geothermal or geoexchange heat pump systems, are becoming more widely accepted in the commercial building sector. Existing ASHRAE design manuals (ASHRAE 1995; Kavanaugh and Rafferty 1997) have greatly advanced the state-of-the-art for design. However, they do not adequately cover technical information needed at the project implementation stage, such as special requirements for commissioning, preventive maintenance, and system troubleshooting.

As more systems enter service, scattered problems have surfaced in operating buildings. ASHRAE Technical Committee TC 6.8 has directed efforts to the production of a commissioning, preventive maintenance, and troubleshooting guide for commercial GSHP systems to serve as a companion guide to the existing design manuals. Guidance in these areas will ensure that GSHP systems deliver the energy efficiency and maintenance savings relative to competing HVAC systems that are characteristics of these systems.

COMMISSIONING

Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent. Commissioning often doesn't get done because owners want to keep the costs down. This guide will present the commissioning requirements for GSHP systems in the design and program, construction, and acceptance phases of a commercial project.

PREVENTIVE MAINTENANCE

Preventive maintenance ensures the proper operation of a system or equipment. The objectives of a preventive maintenance program are to ensure the durability, reliability, efficiency, and safety of the system or equipment. In a new building project, functions and resources must be planned, budgeted, and scheduled. A recent investigation (Cane and Garnet 1999) concluded that a large variance of maintenance costs suggested the need for GSHP system generic maintenance guidelines. Some owners were doing too much maintenance—unnecessary work that negatively impacts GSHP cost-effectiveness. This guide presents maintenance program actions and frequency for the major GSHP system components—the heat pumps, the ground loop, the water well—which, in the absence of manufacturer information, can serve as the basis for a preventive maintenance program.

TROUBLESHOOTING

In spite of all efforts to properly install and maintain the GSHP system, equipment will break down and require fixing. Efforts over the past few years (Cane et al. 1996, 1998; Downey and Proctor 1998) have identified equipment failures, operational problems, and fixes for GSHP systems. This guide contains troubleshooting procedures for the four major subsystems making up a GSHP system. The troubleshooting section characterizes the symptoms, possible causes, and remedies or corrective actions for 32 problem areas. This information provides an excellent tool for system operators and practitioners to use in troubleshooting and fixing commercial GSHP systems.

HOW TO USE THIS GUIDE

Chapter 2 describes the process of commissioning ground-source heat pump systems in large buildings. The introduction identifies the key players and their roles and responsibilities. The chapter then details the commissioning activities in the design and program phase, the construction phase, and the acceptance phase. Sidebars or tables are used throughout Chapter 2 to serve as reminders of items related to commercial ground-source heat pump design, prefunction checks, and functional testing around which a commissioning specification can be written.

Chapter 3 details preventive maintenance requirements for large ground-source systems. Maintenance frequency and actions are provided for heat pump units, fan-coil units (for central systems), and ground-loop and groundwater system components. These have been derived from manufacturer recommendations but are not intended to replace specific manufacturer requirements where available.

Chapter 4 presents a troubleshooting guide for large ground-source heat pump systems. A total of 34 symptoms, with an even greater number of possible causes, are presented for the reader. In the case of each possible cause, there is a proposed remedy. A numbering system is included to guide the reader between these tables and an appendix that provides detail on selected proposed remedies.

CONTEXT

In Chapter 2, we maintain that the architect/design engineer (A/E) can act as the commissioning authority on GSHP systems, particularly in smaller buildings, because of their inherent simplicity. In larger buildings, this is only realistic if the A/E has detailed system knowledge, experience in planning and documenting test procedures, extensive field experience, and good communication skills. If this is not feasible a separate commissioning authority should be hired by the owner. Throughout the text the use of "commissioning authority" may be interchanged with A/E if the intent is that the A/E will act as the commissioning authority.

Chapter 2
Commissioning

Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent. In this context, the primary goal of this chapter is to document the necessary steps to ensure that the design intent is appropriate, understood, and fully implemented and that the implementation can be verified to the satisfaction of the owner.

The chapter is structured as follows.

- Introduction: commissioning and the GSHP system
- Design and program phase activities
- Construction phase activities
- Acceptance and post-acceptance phase activities
- Conclusion

Throughout this chapter, the term "A/E" is used to refer to the design team, including the architect and mechanical/electrical engineers.

INTRODUCTION TO THE COMMISSIONING PROCESS

For conventional systems, commissioning is often not done because owners and developers want to keep first costs down. As systems have become more complex over time, fully functional operation is unlikely without implementing an organized commissioning process. Thus, commissioning has become important in achieving some important objectives:

1. Ensure that the owner's intent is understood and translated into a buildable, testable, and maintainable system.
2. Provide a way to ensure that indoor air quality, efficiency, building code, and similar issues are fully reflected in the design and construction of the structure.
3. Enable a quality-focused approach to be implemented.
4. Clarify, from a legal perspective, the roles and responsibilities of each participant in the construction and installation process.

The Commissioning Process

There are several distinctions between commissioning and customary test-and-balance approaches. Commissioning is a process rather than a discrete activity. It focuses on the system as well as the individual components, and the focus is to deliver both verified performance and accountability. The process of commissioning as developed in this chapter is presented in Table 2-1.

Table 2-1
Summary of Commissioning Process[a]

Function	Performed by	Reviewed by	Witnessed by
Program and Design Phase			
Document Owner's Program, Design Intent, and Basis of Design	A/E		
• Develop the Commissioning Plan	Commissioning authority		
• Develop the Commissioning Specification	Commissioning authority		
• GSHP - Specific commissioning topics	A/E	Commissioning authority	
Construction Phase Activities			
• Synchronize Commissioning Plan with design changes	Commissioning authority		
• Construction, installation, and prefunctional testing	Contractor/TAB	A/E, commissioning authority	
• Startup and initial operation	Contractor/manufacturer		Commissioning authority
Acceptance Phase Activities			
• Functional testing	Contractor/manufacturer	A/E	Commissioning authority
• Verification	Commissioning authority	A/E	
• Complete the commissioning report	Commissioning authority	A/E	
• Complete the systems manual and record documentation	Contractor	A/E, commissioning authority	A/E, commissioning authority
• Train the operation and maintenance staff	Contractor/manufacturer		Commissioning authority

a. **Principal Commissioning Sources.** Principal documents in the commissioning area are ASHRAE (1996) and PECI (1998). These two documents are designed for large complex buildings. Thomas and Madgett (2000), a detailed guide specification for U.S. federal ground-source projects, gives generic language for many parts of projects but has little on commissioning per se.

This chapter distills the essence of these documents, tailored to the relative simplicity of ground-source heat pump systems. Thus, it does not include all of the steps covered in these documents but provides guidance appropriate to GSHP commissioning.

Note: "A/E" and "commissioning authority" are separate entities in Table 2-1. Where the building is relatively small or the A/E is qualified, willing, and compensated, the commissioning authority can be the A/E. Table entries would change appropriately.

Proponents maintain that using a commissioning process has significant legal advantages.[1] A carefully drawn commissioning specification can clarify the engineer's responsibilities and legal liabilities. This includes legal exposure at the work site with respect to safety and other issues. It has been shown that disciplined commissioning can save money in the long term and avoid major problems that can lead to legal claims.

Consequently, a small industry has developed that advocates and does commissioning. Proponents generally recommend engaging an independent "Commissioning Authority" for large commercial/institutional buildings with complex equipment and control systems, particularly for government owners.

This guide advocates an alternative approach for buildings served by GSHP systems, an approach based on the inherent simplicity of GSHP systems. We maintain that commissioning lies within the traditional responsibility of the design engineer when a disciplined design and construction program, focused on simplicity, is applied to GSHP systems, particularly in small buildings. A separate commissioning authority should not be needed for these GSHP systems. The key is to minimize complexity and seek simplicity for performance, control, efficiency, and maintainability. However, this approach in larger buildings is only realistic if the following conditions apply:

- The designer's personnel must have detailed system knowledge, have experience in planning and documenting test procedures, have extensive field experience (the on-site person must be comfortable being in the field), and have good communication skills.
- The commissioning responsibilities need to be included in the designer's terms of reference and be compensated for.

If this is not feasible, a separate commissioning authority should be engaged by the owner and the roles and responsibilities of the various players would be as depicted in Table 2-1. Otherwise, the commissioning authority would be replaced by the A/E in Table 2-1.

GSHP System Components

In this discussion, the following system architecture is assumed.

Ground System. The ground system can be either a horizontal ground heat exchanger, vertical ground heat exchanger, or a groundwater well system. The purpose of the ground system is to reject or absorb heat to or from the ground or groundwater. The components of the ground system include the ground heat exchanger or wells, run-outs, headers, manifolds, flow control valves, pumps, strainers, and plate-frame heat exchanger (for well systems).

Distribution System. The distribution systems includes the piping that distributes the ground energy to the heat pumps and the ductwork that distributes the

1. Hornreich (1994); Tyler (1994).

warm or cold air from the heat pumps to the conditioned space. The distribution system is largely piping with zone ducts when small packaged heat pumps are distributed throughout the building and piping and fan-coils when central heat pumps are employed. These systems are known as "distributed" and "central station," respectively. The distribution system, therefore, includes piping, pumps, expansion tank, air vents, ductwork, supply diffusers, return grilles, flow control dampers, and fire dampers.

Heat Pump Unit. The heat pump unit consists of the heat pump, with all its ancillary equipment, such as hose kits, valves and controls, thermostat, electrical disconnect, etc.

Ventilation System. This is the system that supplies outside air to the building. Typically, the ventilation system consists of an outside air intake, heat pump or other conditioning means and energy recovery ventilator (ERV), ductwork, control dampers, fire dampers, and controls. Since an exhaust air system is required for the ventilation system to supply adequate air, it is really an integral part of the ventilation system, even if no ERV is fitted. Exhaust air systems are made up of exhaust grilles, ductwork, fans, and dampers. In many situations, separating ventilation air and its preconditioning from control of conditions within zones simplifies systems.[2]

Table 2-2 presents an example ground-source specific commissioning process showing functions, roles, and responsibilities of the various players for the case where the commissioning authority and A/E are separate entities. Where the A/E is qualified, willing, and compensated, the commissioning authority would be the A/E in Table 2-2 and in the text that follows in this chapter.

PROGRAM AND DESIGN PHASE ACTIVITIES

Four commissioning tasks prior to construction are necessary. These are (party responsible):

1. Gain agreement on the owner's objectives in terms of physical parameters (temperature, relative humidity in spaces), occupancy needs, energy consumption, etc. Document the design intent accordingly, and formalize it further in a document giving specific technical criteria (A/E).
2. Begin developing the Commissioning Plan as a verification instrument (commissioning authority).
3. Develop the Commissioning Specification (commissioning authority).
4. Check that the *design review* process accommodates commissioning. This includes verifying that the design will achieve the design intent, that the schedule allows commissioning, and that the documents include the commissioning process (commissioning authority).

2. Coad (1996).

Table 2-2
Example Ground-Source Commissioning Process for Mechanical Design

System	Function	Performed by	Witnessed by
Heat Pump Water Piping	Pressure test, clean, fill and purge air	Contractor	A/E
Ground-Source Piping	Pressure test, clean	Contractor	A/E
	Fill and purge air	Contractor	–
Pumps	Inspect, test, startup	Contractor	–
Heat Recovery Unit	Inspect, test, startup	Manufacturer	Commissioning Authority
	Provide clean set of filters	Contractor	–
	Staff instruction	Manufacturer	Commissioning Authority and Owner Representative
Heat Pump Units	Inspect, test, startup	Manufacturer	–
	Provide clean set of filters	Contractor	–
	Staff instruction	Manufacturer	Commissioning Authority and Owner Representative
Chemical Treatment	Flushing and cleaning	Contractor	A/E and Commissioning Authority
	Chemical treatment	Contractor/manufacturer	–
	Staff instruction	Manufacturer	Commissioning Authority and Owner Representative
Air and Water Balancing	Balancing	TAB Contractor	–
	Spot checking	TAB Contractor	A/E and Commissioning Authority
	Follow-up site visits	TAB Contractor	Commissioning Authority
Controls	Contractor installation/commissioning	Contractor	–
	Staff instruction	Commissioning Authority	Commissioning Authority and Owner Representative
	Performance testing	Commissioning Authority	–
	Seasonal testing	Commissioning Authority	–

Note: A/E and commissioning authority are separate entities in Table 2-2. Where the building is relatively small or the A/E is qualified, willing, and compensated, the commissioning authority can be the A/E. Table entries would change appropriately.

Document the Owner's Program, Design Intent, and Basis of Design

ASHRAE (1996) subdivides the beginning of the commissioning process into three initial stages:

1. Owner's Program
2. Design Intent
3. Basis of Design

The Owner's Program lays down the intended uses of the building and the performance expectations such as energy consumption and comfort specifications. The Design Intent is a more detailed description of the Owner's Program. ASHRAE (1996) gives a suggested table of contents for a Design Intent document. From this table of contents, the items applicable to ground-source systems are:

1. Functional use of facility
2. Occupancy requirements
3. Quality of materials and construction
4. Environmental and air quality requirements
5. Energy performance criteria
6. Description of all operating systems
7. Statement of each system's operation under normal occupancy, partial occupancy, emergency situations, etc.
8. Acceptable performance criteria and operating strategy for each system
9. Defined limits and restrictions for the facility
10. Warranty issues
11. Budget considerations and limitations

The Basis of Design is the formal list of all the technical criteria required to meet the Design Intent. The owner should indicate an interest, preference, or requirement for a GSHP system within either of these documents. Alternatively, the designer may have undertaken the investigation as part of evaluating HVAC options. In either case, the interest, preference, or requirement should be included in the Design Intent or the Basis of Design.

Begin Development of the Commissioning Plan as the Verification Instrument

The Commissioning Plan is the overall plan, developed before or after bidding, that provides the structure, schedule, and coordination planning for the commissioning process. The Commissioning Plan is an evolving document, outlined in the earliest phases of the project and given greater detail as the design becomes more specific and construction proceeds. In the earliest stages, the Commissioning Plan is conceptual, focusing on what is required to commission the systems being considered and who is to be involved in commissioning. One goal of formalizing the process is to heighten awareness that the owner and the owner's facility management and maintenance personnel have an important role to play. This role is in approving systems, ensuring that the plans for their placement and installation allow maintenance, and that the need for proper training and documentation requirements are included in the Commissioning Plan.

ASHRAE (1996) includes a list of 18 components of the design-phase Commissioning Plan. They range from developing the detailed requirements for the Commissioning Specification (CSI Specification 17100) to sample document and manual formats.

Develop the Commissioning Specification

The Commissioning Specification is the document that stipulates what testing will be done and by whom, when, and with what supervision. A sample Commissioning Specification is given in ASHRAE (1996), and a more detailed version is given in PECI (1998) in the context of commissioning the HVAC system (Division 17100). Appendix A-1 of this publication is a simplified Division 17100 guide for ground-source heat pump systems. However, additional commissioning requirements are also found in other divisions. These include Division 2 (site work), Division 3 (borehole grout for GSHP systems), Division 15 (HVAC systems), and Division 16 (electrical).

Contractor responsibilities related to commissioning will include

- incorporating commissioning activities into the overall construction schedule and informing the commissioning agent;
- carrying out prefunctional tests and equipment startup in accordance with checklists or procedures in the Commissioning Plan, and included in the specifications as appropriate;
- Coordinating schedule with the commissioning agent;
- operating equipment and systems under the direction of the commissioning authority so that the commissioning authority can witness the functional performance tests and verify operation and performance;
- being responsible for testing, adjusting, and balancing work for hydronic and air distribution systems (subcontract to specialist balancing agency).

The commissioning-related work to be done by the contractor will be included in all the sections and divisions of the specification that relate to the systems being commissioned.

Appendix A-2, from the table of contents of Thomas and Madgett (2000), suggests the large range of topics that might require commissioning attention for complex systems. It is expected that relatively few of these areas will be included in typical GSHP design documents. Even as early as the design phase of the project, the Commissioning Plan and the Commissioning Specification should note the required construction checks and the variety of acceptance tests that may be required.

GSHP-Specific Commissioning Topics

Requirements for commissioning the GSHP-specific components (heat pumps, water loop(s), and ground system) are outlined in CSI Division 15, Sec-

tion 15995. Prefunctional tests are in Section 15997 and functional tests in Section 15998. Critical issues for GSHP systems include:

Interior Details. This includes piping layout (topology and sizes), pumps and controls, air vents, strainers, expansion tanks, makeup lines (and meters), etc.[3] Sidebar 2a lists some issues and resources.

Heat Pumps. In general, ground-source heat pumps should be extended range (formerly called ARI-330, now ISO 13256-1 Ground Loop Heat Pumps). "ARI-320" (ISO 13256-1 Water-Loop Heat Pumps) are rated under a very narrow set of liquid temperatures (86°F standard cooling, 68°F standard heating) and are not considered appropriate for ground-source applications.

GSHP units should be high efficiency with a recommended minimum EER of 14. On an annual energy basis, most commercial systems reject more heat to

Sidebar 2a: Commissioning Issues for Interior Details

- Review pipe sizing and layout to ensure low pressure drops and adequate flow for all heat pumps. Make sure branch lines and hose kits are adequately sized.
- Minimize air vents in pipe systems. Avoid piping configurations that require a vent at each heat pump. Use manual rather than automatic vents.
- Strainers central (in mechanical room) or distributed (at each heat pump). Consider maintenance implications of strainers at plenum-mounted heat pumps.
- Expansion tank (if any) properly located and adequately sized.
- Meter and appropriate backflow prevention valve on makeup water line, if so equipped.
- Circulating pump, variable-frequency drive (if applicable), and controls.
- Chemical treatment of closed-circuit fluids (check properties).
- Antifreeze concentration.
- Adequate flow balancing devices (circuit balancers).
- Adequate slope in condensate drains.
- Integrity of pipe and duct insulation.
- Interference with other services.
- Check that proper service space is provided around equipment.
- Check that all heat pump safety devices are installed.

3. ASHRAE (1995); Kavanaugh and Rafferty (1997).