INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1817-TRP, Long-term temperature change of ground heat exchangers

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution have expressed interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject.

Sponsoring Committee: TC 6.8, Geothermal Heat Pump and Energy

Budget Range: $210,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: April 1, 2020 or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, Monday, December 16, 2019. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: 1817-TRP, “Long-term temperature change of ground heat exchangers”, and “Bidding Institutions Name” (electronic pdf format, ASHRAE’s server will accept up to 10MB)

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

For Technical Matters
Technical Contact
Scott Hackel
Seventhwave
431 Chamany Drive
Madison, WI 53719-1234
Phone: 608-210-7129
E-Mail: shackel@slipstreaminc.org

For Administrative or Procedural Matters:
Manager of Research & Technical Services (MORTS)
Michael R. Vaughn
ASHRAE, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329
Phone: 404-636-8400
Fax: 678-539-2111
E-Mail: MORTS@ashrae.net

Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by December 2, 2019 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below. ALL electronic proposals are to be sent to rpbids@ashrae.org.

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. Hardcopy submissions are not permitted. In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, December 16, 2019. NO EXCEPTIONS, NO EXTENSIONS.

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required) ASHRAE Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.
State of the Art (Background)
Most commercial GSHPs reject more heat to the ground than they extract over the course of a year. Over a decade or less, this can elevate the average ground temperature and therefore reduce GSHP cooling efficiency. GHX design methods that are widely used do attempt to account for this long-term temperature change. The total amount of heat rejected/extracted from the ground is accounted, and the effect of the balance on the ground is calculated using the conductivity and heat capacity. However, there are other important variables controlling the temperature change that are poorly understood; the impact of heat induced moisture migration, groundwater flow, and phase change have not been adequately addressed. The positive cooling effect of evaporation and the potential negative impact of reduced conductivity due to lower moisture concentration are complex and not incorporated in current design methods. Likewise, the impact of moisture freezing in cold-climate applications has not been widely addressed in the design of vertical GHXs.

Two general GHX sizing approaches are recognized in the ASHRAE HVAC Applications Handbook, Chapter 34. The first method uses the cylindrical-heat-source analytical solution (Ingersoll, et. al. 1954). The cylindrical-heat-source method addresses long-term temperature change by adding a temperature penalty \( \tau_p \) to the design entering fluid temperature. The penalty can be calculated, or estimated using a table in the handbook. The other common approach given in the handbook for sizing GHXs uses g-functions (ASHRAE, 2015). With this method, the temperature penalty is implicitly accounted for in the calculation of thermal interference among boreholes. Software tools are used to implement these approaches.

The estimation of long-term temperature change by the two methods discussed above has not been adequately verified with field data. Kavanaugh (2012) did examine GHX performance in 40 commercial buildings with vertical GHXs and between 5 and 25 years of operation. The data collected was limited to approach temperatures and other more static data and was not able to be compared to either of the design methods or long-term temperature change predictions discussed above. Cullin (2015) also investigated temperatures in four operating GHXs. However, none of the systems investigated were significantly unbalanced (and so temperature did not change significantly over time) and the systems were only monitored for 1-2 years.

Justification and Value to ASHRAE
Ground source heat pumps have emerged as one of the most efficient ways to heat and cool buildings. This technical research will create information that will allow for more accurate sizing of these systems. Designers will be able to refine their design approach because they will have a better understanding of how to compensate for long-term ground temperature change.

In one research project, Ruan (2010) estimated that up to 30% of vertical GHXs are significantly oversized. In those cases, application of this research could potentially reduce the size and cost of the GHX. This will in turn allow more GSHPs to be deployed.

It is also possible that the lack of information is leading to GHXs that are too small, which compromises energy performance, dependability, and possibly comfort.

ASHRAE literature will be directly updated as a result of this study. The GSHP design guide (Kavanaugh 2014) in the ASHRAE bookstore is one of ASHRAE’s most popular and well-used special publications. It would benefit from this additional data. The handbook chapter on geothermal utilization (Applications Handbook Chapter 34) could also be updated.

Objectives
To alleviate the gaps in knowledge described above, we propose primary research be conducted to provide data and evaluate the two existing long-term temperature change prediction methods.

The primary objective of this research would be to improve methods for designing GHXs, by improving our understanding of their long-term performance.

Secondary objectives that will fulfill the primary objective include:

• Test the accuracy of the current long-term temperature change calculation methods against field
data from installed GHXs.

- Develop improvements to the long-term temperature change prediction methods, and subsequently their impact on design safety factors. Provide information needed to improve the accuracy of these methods, including descriptions/characteristics of formations that may contribute to or mitigate long-term temperature change.

- A final objective would attempt to validate existing site measurement for at least three new GSHP installations, to lay the foundation for a future study to conduct an even more accurate test of long-term temperature change than this proposed study.

Scope:

PHASE 1

1. Conduct a comprehensive literature review of relevant publications.
   a. Include material from the design of GHXs and relevant literature from studies of heat transfer and storage in soil and rock from other fields of study.
   b. The review should help to understand which type of thermal phenomena are not fully captured in current sizing methods and quantify the magnitude of these elements. For example: heat transferred in groundwater movement, evaporation of groundwater, heat transfer not captured in the simplified radial-only methods, and other phenomena.
   c. The results of the review would be an order-of-magnitude comparison of these potential factors, with the most attention paid to factors that have the largest impact or are potentially measurable. Those more critical factors shall be considered in Task 2 selections.

2. Identify GHXs for possible field study of long-term temperature changes. Criteria for acceptable GHXs include two groups:
   a. Those with data acceptable for collecting and using in analysis for the objectives of this research project:
      i. In operation for at least seven years. Ten years or more would be better.
      ii. Continuous monitoring of heat transfer to the ground. Fluid flow, entering fluid temperature, and return temperature, are all required to be monitored sub-hourly during this period, with limited interruption. Trending of all of this information would need to be available from the outset of building occupancy.
      iii. Successful thermal conductivity testing data available, completed prior to GHX installation, with detailed well logs of geologic formations. Ideally sites will be chosen with a variety of ground properties across the typical ranges.
      iv. A significant temperature difference (>5°F) between entering and return temperatures during a significant majoritiy (~75%) of the heat transfer.
      v. Heavily cooling-dominated loads: some amount of long-term increase would need to be observed in the temperature returning from the GHX.
      vi. Owners are willing to share the data from their systems.
   b. Those that will likely meet all criteria from (a), but which are too new to be used in this research (i.e. new buildings with all the right data monitoring in place) or are still under construction. These buildings should be tracked for future research.

The TC research subcommittee already has a list of 4-8 buildings that could fit these criteria. When the project is awarded we will solicit the broader TC membership to build a larger list of prospects to provide to the contractor. In addition, the contractor will likely need to identify additional installations for a successful research project. When combined these sources will certainly yield more than the ten required buildings, but the contractor will need to further screen the list based on all criteria in 2(a) and eliminate any that do not comply.

3. Conduct an uncertainty analysis on the type of monitoring observed in the short list.
   a. For the values in 2a, estimate the uncertainty of each data point, and how much that uncertainty would contribute to both sides of a comparison between:
      i. a predicted long-term temperature increase based on the measured loads on the GHX and other observed factors such as ground properties, and
ii. the measured long-term temperature increase.

b. Estimate the total combined uncertainty in that comparison
c. Present this result to the Project Management Subcommittee (PMS)

**Go / No-go decision point:** At this stage, the PMS will vote on whether the project has enough good data to proceed. Two primary objectives will need to be fulfilled to pass this go/no-go point:

1. A significant enough list of GHXs – approximately ten – must be identified and confirmed to fit all criteria in 2(a) above and have some level of diversification in siting.

   The uncertainty analysis needs to suggest that the results of analysis will yield useful lessons for the design community related to estimating long-term temperature change in GHXs

   *If the PMS decides not to proceed, the project will be closed out at this point.*

2. **PHASE 2 (assuming the go/no-go point is passed)**

   4. The list of GHXs from 2(a) must be narrowed to those that are likely to yield a low enough level of uncertainty to make meaningful comparisons (for example, see the comparison detailed in Phase 1, task 3a). From the list of GHXs identified in step 2 and the uncertainty analysis conducted in step 3, eliminate GHXs that do not achieve reasonable levels of uncertainty. The temperature difference criterion in 2(a-iv) is likely to be the decisive factor.

   5. Data shall be compiled for all these GHXs into a common database. Data sets shall include the following points:

      **One-time data points**
      i. Thermal conductivity test results
      ii. Any available local hydrogeology data
      iii. Fluid composition
      iv. GHX design drawings and schematics, or equivalent documentation of geometry and materials (including bore depth, pipe size/material, grout material, etc.)
      v. [Only if available] Well log data
      vi. Total GHX flow rate
      vii. Entering and return fluid temperatures
      viii. [Only if available] Fluid pressures
      ix. [Only if available] Flow rate of individual GHX legs
      x. [Only if available] Fluid temperature at any other points in the GHX

      If other design information is readily available such as design loads, basis of design, or other documentation they should be compiled as well, but are not required for a viable site. Data quality should be verified in some way. In many cases, the data points may have been verified by either an independent M&V exercise of the building, or even a prior research study (for example, a number of buildings on the initial shortlist were monitored and validated as part of ARRA-funded research). In these cases those M&V or research reports suffice for validation, and the contractor may collect data remotely.

   6. The data shall be analyzed for comparison with current methods of GHX design, including calculation and design for long-term temperature change.

      a. For each GHX retained in step 5, evaluate the long-term temperature change using the two design methods provided in the ASHRAE handbook.

      b. Conduct a comparison of the measured data to these current methods. Primary comparisons shall be analytical and graphical. Secondary comparisons that use numerical modeling could supplement those primary comparisons. As a result of this analysis, evaluate the current calculation methodologies.

      c. Compare the measured temperature change results with the magnitudes of impacts from ‘other’ heat transfer phenomena in the literature review. Estimate the contribution from ‘other’ heat transfer phenomena identified in 1(b) to the observed temperature changes in GHXs, including local geologic considerations. Quantify their impact on the accuracy of current design methods. Numerical modeling will be useful in determining the impact of individual (uncoupled) heat transfer phenomena.

   **PHASE 3**
7. Validate existing site measurements for at least three new GSHP installations. All data points from step 5 above shall be field-validated. This third step would lay the foundation for a future research on long-term temperature change that could have even more accurate and far-reaching impacts than this study.
   a. Develop a plan for monitoring sites for study of long-term temperature change (includes data points list, basic sensor requirements, etc.)

Use the short list of future GHX for study from 2(b) as a starting point, though all GHXs for this stage would need to use monitoring and data collection systems that are connected to the cloud.
   a. ASHRAE RP funding can be used for some nominal fees for this connection to cloud services.
   b. Add other GHXs to that list based on others that have been identified as the research progressed.
   c. Secure agreement from the building owner to participate in the study.
   d. Validate site measurement using separately calibrated sensors for temperature and flow rate.
   e. Instruct the operators of these sites to track performance and note any changes in operation over time.

8. If time allows in the research, collect and save a small amount of the initial data from any of these sites to serve as the start of the future data set, establishing the format and a clearer starting point for the next research project.

**Deliverables:**

a. Interim Reports

   An interim report will be required at the end of each of the first four major tasks. These interim reports can be written in such that they can easily be incorporated into the final report. They will give the PMS adequate information on the progress of the project to help manage it.

   The most important interim report will come at Project Milestone #2, when there is a Go/No-go decision point to be made by all project stakeholders. This report will describe the outcome of the second task and the potential for further research, identify the sites for further study, and show the uncertainty analysis. This interim report will be used for project stakeholders, and ultimately the PMS, to make the Go/No-go decision.

   Required ASHRAE quarterly progress updates must also be delivered.

   Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the deliverables (“Deliverables”) under this Agreement and shall be provided as follows:

b. Progress and Financial Reports

   Progress and Financial Reports, in a form approved by the Society, shall be made to the Society through its Manager of Research and Technical Services at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

   The following deliverables shall be provided to the Project Monitoring Subcommittee (PMS) as described in the Scope/Technical Approach section above, as they are available:

   Furthermore, the Institution’s Principal Investigator, subject to the Society’s approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

c. Final Report

   A written report, design guide, or manual, (collectively, “Final Report”), in a form approved by the Society, shall be prepared by the Institution and submitted to the Society’s Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement, including a summary of the control strategy and savings guidelines. Unless otherwise specified, the final draft report shall be furnished, electronically for review by the Society’s Project Monitoring Subcommittee (PMS).
Tabulated values for all measurements shall be provided as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for correction).

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

- An executive summary in a form suitable for wide distribution to the industry and to the public.
- Two copies; one in PDF format and one in Microsoft Word.

d. **Science & Technology for the Built Environment** or ASHRAE Transactions Technical Papers

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the “ASHRAE Manuscript Central” website-based manuscript review system in a form and containing such information as designated by the Society suitable for publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in “Manuscript Central” for an ASHRAE Transactions Technical or HVAC&R Research papers. The paper title shall contain the research project number (1817-RP) at the end of the title in parentheses, e.g., (1817-RP).

All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

e. Measured data

All the data collected from the sites (in Task 3) will also be provided as a primary deliverable. This data can be provided as an appendix to the final report (for measurements which are adjusted by correction factors, corrected results and method used for correction must also be provided), in electronic format.

Data is defined in General Condition VI, “DATA”

f. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

**Level of Effort**

Estimated $ Value Range: Total $ 210,000
Prior to go/no-go: $50,000
Duration in Months: 20
Professional-Months, Principal Investigator: 2.5
Professional-Months, Total: 14
Project Milestones:

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<tr>
<th>No.</th>
<th>Major Project Completion Milestone</th>
<th>Deadline Month</th>
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<tbody>
<tr>
<td>1</td>
<td>Present a vetted list of buildings for which quality data appears available, along with an uncertainty analysis for the remaining tasks.</td>
<td>6</td>
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<tr>
<td>2</td>
<td>Go/No-go decision by committee for overall project based on the results from Milestone 1 and general progress and success thus far.</td>
<td>8</td>
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<tr>
<td>3</td>
<td>Prepare final report documenting findings and deliverables from Phases 1 and 2.</td>
<td>15</td>
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<tr>
<td>4</td>
<td>Completion of Phase 3 work, supplemental report to committee outlining the use of the data from the validated sites.</td>
<td>19</td>
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Proposal Evaluation Criteria

Proposals submitted to ASHRAE for this project should include the following minimum information:

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<tr>
<th>No.</th>
<th>Proposal Review Criterion</th>
<th>Weighting Factor</th>
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<tbody>
<tr>
<td>1</td>
<td>Contractor’s understanding of work statement as expressed in proposal</td>
<td>15%</td>
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<tr>
<td>2</td>
<td>Quality of methodology proposed for conducting research</td>
<td>30%</td>
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<tr>
<td>3</td>
<td>Qualifications of personnel for this project</td>
<td>25%</td>
</tr>
<tr>
<td>4</td>
<td>Student involvement c. Reasonableness of project schedule</td>
<td>3%</td>
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<tr>
<td>5</td>
<td>Probability of meeting the objectives and schedule of the Work Statement</td>
<td>27%</td>
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References