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Michael R. Vaughn, P.E.
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TO:	Scott Hackel, Chair TC 6.8, shackel@seventhwave.org Jeffrey Spitler, Research Subcommittee Chair TC 6.8, spitler@okstate.edu Scott Hackel, Work Statement Author(s),
FROM:	Michael R. Vaughn, Manager of Research and Technical Services (MORTS)
CC:	Omar Abdelaziz, Research Liaison 6.0,
DATE:	June 18, 2019
SUBJECT:	Work Statement (1817-WS), "Long-term temperature change of ground heat exchangers"

During their recent pre-annual meeting, the Research Administration Committee (RAC) reviewed the subject Work Statement (WS) and voted 11-0-0 to conditionally accept it for bid provided that the RAC approval conditions below are addressed to the satisfaction of your Research Liaison in either written responses or revisions to the work statement.

See the approval conditions below.

1. There is a Go/No-Go point described but the fee is not broken down to be aligned with this decision point. If the project is stop, what amount would the contractor be paid?
2. Need a specific cost budget.
3. Provide more information on the GHX list (10) before starting.

The WS review summary also contains comments from individual members of RAC that the TC may or may not choose to also consider when revising the WS; some of these comments may indicate areas of the WS where readers require additional information or rewording for clarification.

Lastly, please provide ASHRAE staff with the final names and contact information for the Proposal Evaluation Subcommittee (PES) roster, and the Technical Contact that will respond to questions from prospective bidders during the bid posting period (typically this is a WS author or PES member). The technical contact and all members of the PES must also agree to not bid on this project directly or through their employer as the primary contractor or a subcontractor.

Please coordinate changes to this Work Statement with your Research Liaison, Omar Abdelaziz RL6@ashrae.net or omar.abdel.aziz@gmail.com. Once he is satisfied that the approval conditions have been met, the project will be ready to bid.

The first opportunity that you will have for this project to possibly bid is fall 2019. To be eligible for this bid cycle, a revised work statement that has been approved for bid by your research liaison should be sent (electronically) to Michael Vaughn, Manager of Research and Technical Services, mvaughn@ashrae.org or morts@ashrae.net, by **September 1, 2019**. The next opportunity for bid after that will be spring 2020.

Project ID	**1817**	
Project Title	**Long-term temperature change of ground heat exchangers**	
Sponsoring TC	TC 6.8, (Geothermal Heat Pump and Energy)	
Cost / Duration	$180,000 - $215,000 / 20 Months	
Submission History	**2nd WS Submission, 1st WS Returned W19, RTAR Accepted A16**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2019 Spring Meeting Review	**COMPLETE RTAR CHECK LIST CRITERIA BELOW IF RTAR STAGE WAS SKIPPED BY TC**	
RTAR Check List Criteria	**Voted NO**	**Comments & Suggestions**
State-of-the-Art (Background): The WS should include some level of literature review that documents the importance/magnitude of a problem. If not, then the WS should be returned for revision. **RTAR Review Criterion**		
Advancement to the State-of-the-Art Is there enough justification for the need of the proposed research. Will this research significantly contribute to the advancement of the State-of-the-Art. **RTAR Review Criterion**		
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject. **RTAR Review Criterion**		
IF THE THREE CRITERIA ABOVE ARE NOT ALL SATISFIED - MARK "REJECT" BELOW BUT ADDRESS THE FOLLOWING CRITERIA AS APPROPRIATE		
		RTAR STAGE FOLLOWED
WS Check List Criteria - START HERE		**Comments & Suggestions**
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.		
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.		**#1 -** There is a Go/No-Go point described but the fee is not broken down to be aligned with this decision point. If the project is stop, what amount would the contractor be paid.
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		**#1-** Need a specific cost budget, not a range.
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**#6-** Need to validate there is sufficient list of GHx (10) before starting?
Decision Options	**Initial Decision**	**Suggested Approval Conditions**
ACCEPT		**#1 -** The primary uncertainty that is described relates to the presence and movement of ground water/moisture. I question whether it would ever be possible to know the ground water conditions for a given period. Even if the analytical model could accurately account for the water/moisture, it would not be possible to know the data to input into model. To move forward, the WS needs to address this. **#6** - Would like more information on the GHX list (10) before starting.
COND. ACCEPT	X	
RETURN		
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

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March 6, 2019

Dear Manager of Research and Technical Services:

The TC 6.8 Research Subcommittee has revised the work statement 1817 "Long-term temperature change of ground heat exchangers." This work statement had previously been submitted in December 2018 and was returned by RAC with comments following the Atlanta meeting in January 2019.

We have improved the scope of work and fully addressed all of the concerns that RAC posed in their comments:

> *1. Requires full TC vote. The two negative votes do not support the work statement. Hence, only six of the fifteen members voted in support of this WS.*
>
> For the revised work statement, we did a letter vote in which 11 of the 15 members participated, and eight voted to approve, one voted no, one abstained (they were a potential bidder) and the chair non-voted.
>
> *2. The alternate task for the NO-GO decision is not adequately defined.*
>
> We have effectively altered the scope such that if a 'no' decision is reached at the GO/NO-GO point, the project simply ends.
>
> *3. Please clarify the objective/purpose of the laboratory like GHX.*
>
> This is no longer relevant with the changes made as a result of comment 2 above.
>
> *4. One major uncertainty in the proposal is the amount of time and travel that will be required to obtain the sources of data.*
>
> We have described this in greater detail, and described situations in which the contractor may avoid travel. Furthermore, we also added additional description of how the TC will provide information (such as the initial short list of potential sites) that will aid the contractor.

In addition to the four primary comments, we also reviewed all of the other secondary comments from RAC and made a variety of minor changes to address these. They have improved the document.

We revised the work statement accordingly, and the revised version was approved by the TC with a letter vote ending March 6, 2019. The TC voted 8-1-1, with a chair non-vote, in favor of the work statement going to RAC. That's 11 of our 15 voting members. The reason for the single dissention was:

- There is a lack of proper or any documentation of the heat transfer from the building thermal loads, heat pump equipment (sizes), and ground heat exchanger parameters in order to substantiate and delineate ground temperature changes. All of these elements are involved in calculating heat transfer in Geothermal Systems and their details need to be included in research about this Work Statement.

The research subcommittee working on the statement, as well as the eight voting in favor, felt that the only way to conduct this project within a reasonable budget is to place the experimental boundary at the level of the ground heat exchanger, accounting for all building effects by measuring the energy flow into and out of the ground using flow and temperature measurement. That approach also has the advantage of generalizing the results across the wider variety of buildings. The dissenting view is a valid one and would be a possible route to take with the research, but we judged that it would result in a much higher project cost without reasonable return.

Sincerely,

Scott P Hackel
shackel@slipstreaminc.org

WORK STATEMENT COVER SHEET

Date: March 6, 2019

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	X
B Executive Summary	X
C. Applicability to ASHRAE Research Strategic Plan	X
D. Application of the Results	X
E. State-of-the-Art (background)	X
F. Advancement to State-of-the-Art	X
G. Justification and Value to ASHRAE	X
H. Objective	X
I. Scope	X
J. Deliverables/Where Results will be Published	X
K. Level of Effort	
Project Duration in Months	X
Professional-Months: Principal Investigator	X
Professional-Months: Total	X
Estimated $ Value	X
L Proposal Evaluation Criteria & Weighting Factors	X
M. References	X
N. Other Information to Bidders (Optional)	

Title: Long-term temperature change of ground heat exchangers

WS#1817

(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

Applications handbook chapter 34
Systems and equipment chapter 9
Geothermal Heating and Cooling (the Blue Book)

Responsible TC/TG: TC 6.8 Geothermal Heat Pump and Energy

Date of Vote:

For		8
Against	*	1
Abstaining	*	1
Absent or not returning Ballot	*	4
Total Voting Members		15

This W/S has been coordinated with TC/TG/SSPC (give vote and date):

Has RTAR been submitted? Yes

Strategic Plan
Theme/Goals

Work Statement Authors: **

Scott Hackel

Others: Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu, Dennis Koop

S

Proposal Evaluation Subcommittee:

Chair: Scott Hackel
Members: Dennis Koop, Stephen Hamstra, Xiaobing L

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)

TBD

Recommended Bidders (name, address, e-mail, tel. number): **

James Tinjum and Doug Reindl, University of Wisconsin; dreindl@wisc.edu
Ken Seibert, CMTA Engineers
Jeff Spitler, Oklahoma State University; spitler@okstate.edu

Hugh Henderson, Frontier Energy; hhenderson@frontierenergy.com

Western Cooling Center, Univ of California - Davis

(Three qualified bidders must be recommended, not including WS authors.)

Potential Co-funders (organization, contact person information):

IGSHPA (contact: Xiaobing Liu, Liux2@ORNL.gov)
EPRI

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		X	
Has an electronic copy been furnished to the MORTS?	X		
Will this project result in a special publication?		X	
Has the Research Liaison reviewed work statement?	X		

* Reasons for negative vote(s) and abstentions

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1817

Title:

Long-term temperature change of ground heat exchangers

Sponsoring TC/TG/MTG/SSPC:

TC 6.8 Geothermal Heat Pump and Energy Recovery Applications

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

Executive Summary:

Ground-source heat pump (GSHP) systems can achieve high-efficiency by using the relatively low temperature lift between the conditioned space and the ground. GSHP are coupled with ground heat exchangers (GHXs), a network of tubing inserted into the ground by drilling or excavation. An important factor in GHX design is the long-term ground temperature change (i.e. annual non-hysteretic changes in ground temperature caused by unbalanced heating and cooling loads). Existing design methods incorporate a calculation of the long-term temperature change in GHXs, but there is a large uncertainty about how well the calculations reflect installed performance.

Therefore, we propose to conduct analytical and field study of long-term temperature change of ground heat exchangers (GHXs). This long-term temperature change significantly impacts the design length of GHX, so a better understanding of it will reduce design risk, improve system performance, and reduce cost by more accurate sizing. The results of this research project will serve to improve the practice of designing GHXs for all future ground source heat pump systems. Results will be included in future versions of the ASHRAE Applications Handbook Geothermal Energy Utilization chapter and be used to improve the long-term temperature change calculation for GHX designs. Similarly, the results could inform the same design methods in the widely-used ASHRAE publication Geothermal Heating and Cooling. There are also many GHX design software tools used by ASHRAE members, including everything from basic spreadsheets to design software, that could incorporate the findings of this work.

To achieve these results, the research will proceed through the following tasks:

1. Conduct a comprehensive literature review of relevant published and prior knowledge.
2. Identify GHXs for possible field study of long-term ground temperature change.
3. Conduct an uncertainty analysis on the data available for the GHXs identified in task 2.
4. Narrow the list of GHXs from step 2 to those that are likely to achieve reasonable levels of uncertainty.
5. Compile a common database for data from all the GHXs identified in task 4.
6. Analyze data and compare with current methods used in GHX design, specifically with respect to prediction and design incorporating the long-term temperature change. Primarily analytical, and secondarily numerical, methods will be used to evaluate these results in comparison to existing design methods, and suggest improvements to existing methods and literature.
7. Validate existing site measurements at a minimum of three new GSHP installations (newer

installations than those from step 4). All data points from step 5 above shall be validated. This last step would lay the foundation for a future study to conduct an even more accurate test of long-term temperature change than this proposed study.

Applicability to the ASHRAE Research Strategic Plan:

These effects are well aligned with several of the goals of ASHRAE research, as outlined in the Research Strategic Plan:

1. *Support development of tools, procedures and methods suitable for designing low energy buildings.*

   GSHPs are a key strategy for achieving low-energy and net-zero buildings. Accurate, cost-effective sizing of GHXs is an important step in implementing more GSHPs.

2. *Support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety.*

   Better understanding of GHX performance will help properly size it to avoid under-sized GHX and resulting poor performance, or expensive oversized GHX.

3. *Maximize the actual operational energy performance of buildings and facilities.*

   Appropriate sized GHX will lead to better building performance and more importantly, enable wider adoption of GSHP technology by avoiding oversizing of GHXs.

Application of Results:

The results of this research project will serve to significantly improve the practice of designing GHXs for all future ground source heat pump systems. This will enable more high-performance HVAC systems (like GSHPs) to be installed in the future, and for them to be more efficient and cost effective. These ultimate outcomes will be obtained by applying the results of the research to the tools and references that are used by design engineers to design these systems.

First, the results will be included in future versions of the ASHRAE Applications Handbook Geothermal Energy Utilization chapter, which includes the primary design methods used by engineers to design GHXs. The results could ultimately be used to improve the design method's calculation of long-term ground temperature change. Similarly, the results could inform the same design methods in the widely-used ASHRAE publication Geothermal Heating and Cooling.

There are also design tools, including everything from basic spreadsheets to sophisticated commercial software, that contain these design methods (including long-term temperature change factors). These design tools will likely be updated based on this study.

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 t_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.

Advancement to the State-of-the-Art:

The state-of-the-art design approaches discussed above assume a relatively homogenous, low-porosity substrate. Dynamic moisture change effects are not calculated explicitly (Kavanaugh 2003; Kavanaugh and Rafferty 2014). Adjustments are made but the resulting values represent worst-case scenarios. Ideally, temperature change would include groundwater recharge (vertical flow), groundwater movement (horizontal flow) – which can have a significant impact (Chiasson et al. 2000a), evaporation (and condensation) of water in the soil, and freezing of groundwater in cold climates. Because of these uncertainties, the ASHRAE handbook states: "Because these effects have not been thoroughly studied, the design engineer must establish a range of [GHX] design lengths". The proposed research would supply data critical to empirically determining the *collective magnitude* of these impacts (if not differentiating between the different impacts).

This research would also lead to improvement in GHX design. The two methods for sizing GHXs discussed above yield significantly different estimations of the long-term temperature change, and therefore the recommended GHX size (Bernier et al. 2008). Some validation of the two sizing methods has been completed, but essentially only at the daily and seasonal timescales. Estimations of GHX performance diverge significantly in the long-term. This research would allow the two design methods to be compared to outcomes observed in installed GHXs.

In short, research is needed to 1) collect long-term GHX data, 2) evaluate existing design methods, 3) identify and understand discrepancies between the outcomes of current design methods.

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/Technical Approach:

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 (>5ºF) between entering and return temperatures during a significant majority (~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 has already identified a short list of 4-8 building leads that could fit these criteria; when the project is awarded we will solicit the broader TC membership to build a larger list of prospects. The contractor will likely need to identify additional installations for a successful research project.

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)

<u>Go / No-go decision point:</u> 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 that fit all criteria in 2(a) above and have some level of diversification in siting.
2. 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.

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

   Continuous data, from first occupancy

   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.)
   b. 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. ASHRAE RP funding can be used for some nominal fees for this connection to cloud services.
   c. Add other GHXs to that list based on others that have been identified as the research progressed.

d. Secure agreement from the building owner to participate in the study.
e. Validate site measurement using separately calibrated sensors for temperature and flow rate.
f. 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/Where Results Will Be Published:

Deliverables throughout the project will include the following:

<u>Interim Reports</u>
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.

<u>Final Report</u>
A written final report shall be prepared containing complete details of all research, including a summary of the literature review, sites studied, quantitative results, qualitative considerations, and conclusions. The final report will be prepared electronically and hard copies will also be provided.

<u>Measured data</u>
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.

<u>Science & Technology for the Built Environment or ASHRAE Transactions Technical Papers</u>
One or more papers shall be submitted in a form suitable for publication as either Research Papers for STBE or Technical Paper(s) for ASHRAE Transactions.

Depending on the nature of the results, we also may request a technical article suitable for publication in the ASHRAE Journal. This would be a voluntary submission and not a Deliverable.

<u>Level of Effort</u>:

Estimated $ Value Range: Total $ 180,000 – 215,000

Duration in Months: 20

Professional-Months, Principal Investigator: 2.5

Professional-Months, Total: 14

<u>Proposal Evaluation Criteria</u>:

No.	Proposal Review Criterion	Weighting Factor
1	Contractors understanding of Work Statement as revealed in proposal	15%
2	Quality of methodology proposed for conducting research	30%
3	Qualifications of personnel for this project	25%
4	Student involvement	3%

5	**Probability of meeting the objectives and schedule of the Work Statement**	**27%**

Project Milestones:

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

Authors:

Scott Hackel, Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu, Dennis Koop

References:

ASHRAE HVAC Applications Handbook. Chapter 34. “Geothermal Energy Utilization.” ASHRAE, 2015.

Bernier, M.A., A. Chahla, and P. Pinel. 2008. Long-term ground temperature changes in geo-exchange systems. *ASHRAE Transactions* 114(2):342-350.

Carlson, S. 2001. Development of equivalent full load heating and cooling hours for GCHPs applied in various building types and locations. ASHRAE TRP-1120, *Final Report*.

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Cullin, J.R., J.D. Spitler, C. Montagud, F. Ruiz-Calvo, S.J. Rees, S.S. Naicker, P. Konecny, and L.E. Southard. 2015. Validation of vertical ground heat exchanger design methodologies. Science and Technology for the Built Environment 21(2): 137-149.

Kavanaugh, S.P., and J.S. Kavanaugh. 2012. Long-term commercial GSHP performance, part 3. *ASHRAE Journal* 54(9).

Kavanaugh, S.P., and K. Rafferty. 2014. *Geothermal Heating and Cooling: Design of Ground-source Heat Pump Systems*. ASHRAE.

Ruan W., and Horton, W. *Literature Review on the Calculation of Vertical Ground Heat Exchangers for Geothermal Heat Pump Systems*. International High Performance Buildings Conference, Paper 45. 2010.

Other Information for Bidders (Optional):

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

The process seems well thought out. Its possible that RAC could use a bit more representation from practitioners to balance out the many members with research backgrounds.

But by far the biggest area for improvement in this process is this form. It is antiquated in a variety of ways, including being very difficult to paste information into from the RTAR and other sources. The tabs, formats, justification, etc. all seem off. Perhaps it is a Microsoft Word version issue. But the real improvement would be to shift away form using a process that involves filling in boxes in Word, which is never going to work all that well. A free-form Word document (without boxes), an editable PDF, or even a spreadsheet would work better. Some other type of html or java-based approach may be a solution as well.

Shaping Tomorrow's Built Environment Today

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Michael R. Vaughn, P.E.
Manager
Research & Technical Services

mvaughn@ashrae.org

TO: Scott Hackel, Chair TC 6.8, shackel@seventhwave.org
Jeffrey Spitler, Research Subcommittee Chair TC 6.8, spitler@okstate.edu
Omar Abdelaziz, Research Liaison Section 6.0, omar.abdel.aziz@gmail.com

FROM: Michael Vaughn, MORTS, MORTS@ASHRAE.net

DATE: January 23, 2019

SUBJECT: Work Statement (1817-WS), "Long-term temperature change of ground heat exchangers"

During their recent winter meeting, the Research Administration Committee (RAC) reviewed the subject Work Statement (WS) and voted to return with comments.

Below are the issues, concerns, and questions that must be addressed in your next submission of the WS if you choose to resubmit.

1. Requires full TC vote. The two negative votes do not support the work statement. Hence, only six of the fifteen members voted in support of this WS.
2. The alternate task for the NO-GO decision is not adequately defined.
3. Please clarify the objective/purpose of the laboratory like GHX.
4. One major uncertainty in the proposal is the amount of time and travel that will be required to obtain the sources of data.

Please coordinate changes to this Work Statement with your Research Liaison, Omar Abdelaziz, omar.abdel.aziz@gmail.com or RL6@ashrae.org prior to resubmitting it to the Manager of Research and Technical Services for further consideration by RAC.

Also, it is necessary that you provide a new TC vote on the revised Work Statement, and a letter describing how each of the above items were addressed in the revision.

If you wish for this work statement to be reconsidered at the next RAC meeting, the revised Work Statement must be sent (electronically) to Michael Vaughn, Manager of Research and Technical Services (morts@ashrae.net) by **March 15, 2019**. The next opportunity for consideration after this deadline is May 15, 2019.

Project ID	**1817**	
Project Title	**Long-term temperature change of ground heat exchangers**	
Sponsoring TC	TC 6.8, (Geothermal Heat Pump and Energy)	
Cost / Duration	$180,000 - $215,000 / 20 Months	
Submission History	**1st WS Submission, RTAR Accepted S17**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2019 Winter Meeting Review	**RTAR STAGE FOLLOWED**	
Check List Criteria	**Voted NO**	**Comments & Suggestions**
State-of-the-Art (Background): The WS should include some level of literature review that documents the importance/magnitude of a problem. If not, then the WS should be returned for revision. **RTAR Review Criterion**		
Advancement to the State-of-the-Art Is there enough justification for the need of the proposed research. Will this research significantly contribute to the advancement of the State-of-the-Art. **RTAR Review Criterion**		
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject. **RTAR Review Criterion**		
IF THE THREE CRITERIA ABOVE ARE NOT ALL SATISFIED - MARK "REJECT" BELOW BUT ADDRESS THE FOLLOWING CRITERIA AS APPROPRIATE		
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		**12** - only names and affiliation provided. **10** - 5 listed but complete contact info is not provided. **4** - Yes but no specific complete contact information is provided
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		**10**- As described and within the stated scope, the description is correct. However, as the two dissenting members of the TC state, it is not clear how the work described will resolve the wide range of uncertainties resulting for the diverse assortments of confounding factors (e.g., soil properties, hydrology and local climate). Also, it is not clear how a study over a limited span of time (20 months) can address long term effects that may not be measurable over a short span of time (especially as the authors cite the short duration of a previous study of 1-2 years as a shortcoming of that study.) The authors state that they will select only GHX cases that have been in operation for at least 7 years and for which data on the ground HT have been logged (presumably by measuring temperature and flow rates in and out of the HX). However, given that the authors correctly state that changes in soil water flow and hydrology over time is an important factor, it is not clear how changes in the measured ground HX HT rate over time can be correlated with commensurate changes in the ground hydrology or wet soil properties. **5** - Seems high but there is a lot in the bidding tasks
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.		**12** - quite detailed task breakdown and linked well with the milestones and deliverables. **10** - The task breakdown is very detailed. My comments under the project description apply here as well. The authors state that an uncertainty analysis on the data collected in Phase I needs to be conducted. However, the major uncertainties for a GHX may be related to underground unknowns. How are these uncertainties to be estimated -- through extraction of underground soil measurement over time? **13** - The alternate task for the NO GO decision is not adequately defined. What is the objective/purpose of the laboratory like GHX? Is it to be able to produce long term ground temperature changes with measurable results? This alternate task needs further explanation as to its objectives and likely use, with perhaps some guidelines on suggested paths to consider. Task 6a may be difficult to accomplish using the data available from Task 2. Most GHX design software uses the output from building load and equipment sizing calculations to size the GHX system and then estimate the long term temperature changes. While you have focused on identifying the GHX related data, you have not required the building/HVAC system data to be obtained as well. If such software can make use of the available peak GHX heat absorption or rejection data for these calculations, then that is fine.
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.		**12** - however, missing the required quarterly progress updates to MORTS. **10 -** Insofar as the project scope is concerned and subject to the concerns expressed above.
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		**10** - Please see concerns expressed above. It may be worthwhile to use the data collected in Phase I to check the accuracy utility of the existing models, at least practically. **5** - Would like to see the scope reduced to a smaller subset of deliverables. **4** - A couple of NO votes at the TC level indicate that this project will be extremely difficult to do and provide adequate data to make an assessment. My thought is you have to start somewhere to get an understanding that it is possible. There first milestone provides a Go/No Go gate that is appropriate
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		**10** - Not sure, given the concerns expressed above. **4** - I thought this would be a longer term project. It is only 20 months. I would expect you would need to measure data over at least 3 seasons to account for the variability in ambient temps and rain/snow coverage?
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**10** - It can be bid but I concur with the dissenters that the results will not address the deficiencies cited by the WS authors. **13** - One major uncertainty in the proposal is the amount of time and travel that will be required to obtain the sources of data. I suspect the PI will need to personally view and inspect every data site, which could lead to extensive time and travel budgets. Even for a university PI, this part of the project could likely not be assigned to a lower paid graduate student at this stage of the project. The TC may wish to compile a list of likely candidate sites to simplify this process other than just saying they have a short list (does this mean 2?) and help the bidders understand how to bid their time and effort.
Decision Options	**Initial Decision**	**Final Approval Conditions**
ACCEPT		**10 -** The RTAR Box in the cover page is not filled. The 2 negative votes do not support the WS (do not believe the work will be of value to the intended audience). Further, 7 of the TC members did not even vote, so the WS is endorsed by only 6 of 15 members of the TC. Should clarify more explicitly cofunding agency commitments. The challenges in GHX design and long term performance predictions articulated by the WS authors are important and worthwhile. But it is doubtful that the work proposed will lead to the desired outcomes. I suggest that this project be reduced in scope and focused on compiling data for validating the existing models, revealing their shortcomings, and perhaps, pointing to improvements to be made to the model (essentially a rescoped Phase I). With this, I will vote return, otherwise, reject. **7** - I believe that the WS is well written and meets all of the formatting and completeness criteria of RAC. The objective of the research is to address uncertainty with well field design associated primarily with ground water migration and evaporation/condensation along with other factors. My concern with this research is that ground water variation is very localized and it may not be possible to generalize this through enhanced analytical methods. The research plan includes a go/no-go decision stage gate. I would like to see the WS include a discussion of how variations in local conditions vs. analytical methods will be addressed through this research. A 6 yes, 2 no vote with 7 not returning ballots is not a sufficient consensus. There are obviously questions about this research within the TC. WS authors provided very specific feedback on use of WS form that RAC should address. **5** - Would like to address the project scope to a smaller subset. **13** - Be sure task 5 provides all the data needed for all later tasks. Also be clearer on the alternate task from a NO GO decision after Task 3. See if the TC can be more helpful with obtaining likely GHX data sites so a bidder can estimate their effort. **4** - More detail in the bidders list. A couple of NO votes at the TC level indicate that this project will be extremely difficult to do and provide adequate data to make an assessment. My thought is you have to start somewhere to get an understanding that it is possible. There first milestone provides a Go/No_Go gate that is appropriate to prevent this issue.. I thought this would be a longer term project. It is only 20 months. I would expect you would need to measure data over atleast 3 seasons to account for the variability in ambient temps and rain/snow coverage?
COND. ACCEPT		
RETURN		
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

749 University Row
Suite 320
Madison, WI 53705

November 20, 2018

Dear Manager of Research and Technical Services:

The TC 6.8 Research Subcommittee has completed work on work statement 1817 “Long-term temperature change of ground heat exchangers.” This work statement stemmed from a conditionally accepted RTAR; conditional acceptance was communicated to us by RAC on February 10, 2017.

We have significantly improved the scope of work and fully addressed all of the concerns that RAC posed in their conditional acceptance.

1. *Edit objectives for clarity and include step four from the "Expected Approach" section. Funding levels and duration should be estimated for each step to arrive at a total funding amount and duration for the total project.*

   We’ve taken the following actions to address these concerns:
   - Step four from the Expected Approach is now included as an objective.
   - We estimated the funding level more specifically, with divisions for different items.

2. *Need justification for duration and budget.*

   The scope of work is now much more developed and detailed in this version. We have estimated both the duration and the budget based on requirements of each of these subtasks.

   Specifically, regarding cost, the project will incur significant cost for a number of reasons. First of all, outreach to a large number of buildings takes considerable time. In order to find the right person and obtain the necessary information, many inquiries will need to be made for each building, and many leads will result in dead ends. And secondly, for the sites that are identified there will be very large data sets collected. Each of these data sets must be cleaned and QC’ed, be analyzed for uncertainty, and ultimately analyzed in comparison to design prediction.

3. *Make it clear the limiting factors such as climate zone, building size or load characteristics, ground heat transfer non-uniformity.*

   The project only includes study of the GHX. This may at first sound narrowing, but it actually makes the study completely agnostic to climate, building size, or any *building* load characteristics. It is simply focused on the GHX as an entity in itself, and is therefore affected only by the load characteristics on the ground (namely the degree of overheating), and the properties of the ground. We have defined these two elements more specifically in step 5 of the scope of work. This approach means that the results can be applied to any buildings for which our sample of GHXs is representative. If we're successful getting a range of a few geologies and degrees of overheating, the results will be applicable to the vast majority of buildings with cooling-dominated loads (and therefore overheated ground). There was significant discussion amongst TC 6.8 regarding drawing this boundary for the research just around the GHX. Here is one description that I pulled from that discussion thread that I think sums up our intent well:

With such data, we can simply understand the load on the ground based on the history of energy flowing into and out of the ground. Thinking of it as a fundamental thermodynamics problem, it's as if we're drawing a control boundary around the borefield – studying only energy that crosses that boundary. Now, there are a number of things that we can't answer with such a study (ENERGY STAR scores, effect of heat pump selection, pumping and controls, and so on). But those aren't an objective of this particular study, so that is okay. And once we limit to the focus to just the borefield and get more data on that component (namely energy flows over time) we can draw more conclusions even if we end up with fewer buildings in the sample. We do assume we'll have fewer buildings in the sample than the EPRI study, due to the unique requirement of flow rate measurement.

This version has been approved by TC 6.8 in a vote on June 26, 2018 in Houston. The TC voted 6-2-0 in favor of the work statement going to RAC. The two reasons for dissention were:

- I do not support this work statement as I feel that the data may not be accurate enough to use for updating/changing current design procedures.
- It is unclear to me that the work statement as written (including proposed contract value) will provide information to the practicing engineer needed to reduce the uncertainty of GHX calculations.

The six who voted in favor disagreed with these sentiments and feel that there is enough likelihood of success, especially given the way the proposal was written with a go/no-go milestone.

Sincerely,

Scott P Hackel
shackel@seventhwave.org

WORK STATEMENT COVER SHEET

Date: June 15, 2018

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	X
B Executive Summary	X
C. Applicability to ASHRAE Research Strategic Plan	X
D. Application of the Results	X
E. State-of-the-Art (background)	X
F. Advancement to State-of-the-Art	X
G. Justification and Value to ASHRAE	X
H. Objective	X
I. Scope	X
J. Deliverables/Where Results will be Published	X
K. Level of Effort	
Project Duration in Months	X
Professional-Months: Principal Investigator	X
Professional-Months: Total	X
Estimated $ Value	X
L Proposal Evaluation Criteria & Weighting Factors	X
M. References	X
N. Other Information to Bidders (Optional)	

Title: Long-term temperature change of ground heat exchangers

WS#1817

(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

Applications handbook chapter 34
Systems and equipment chapter 9
Geothermal Heating and Cooling (the Blue Book)

Responsible TC/TG: TC 6.8 Geothermal Heat Pump and Energy

Date of Vote: June 26, 2018

For		6
Against	*	2
Abstaining	*	0
Absent or not returning Ballot	*	7
Total Voting Members		15

This W/S has been coordinated with TC/TG/SSPC (give vote and date):

Has RTAR been submitted?
Strategic Plan
Theme/Goals

Work Statement Authors: **

Scott Hackel

Others: Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu, Dennis Koop

K

Proposal Evaluation Subcommittee:

Chair: Scott Hackel
Members: Dennis Koop, Steve Kavanaugh, Stephen Hamstra, Xiaobing L

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)

TBD

Recommended Bidders (name, address, e-mail, tel. number): **

James Tinjum and Doug Reindl, University of Wisconsin
Ken Seibert, CMTA Engineers
Jeff Spitler, Oklahoma State University

Hugh Henderson, CDH Energy

Western Cooling Center, Univ of California - Davis

(Three qualified bidders must be recommended, not including WS authors.)

Potential Co-funders (organization, contact person information):

IGSHPA (contact: Xiaobing Liu, Liux2@ORNL.gov)
EPRI

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		X	
Has an electronic copy been furnished to the MORTS?	X		
Will this project result in a special publication?		X	
Has the Research Liaison reviewed work statement?	X		

* Reasons for negative vote(s) and abstentions

- I do not support this work statement as I feel that the data may not be accurate enough to use for updating/changing current design procedures.
- It is unclear to me that the work statement as written (including proposed contract value) will provide information to the practicing engineer needed to reduce the uncertainty of GHX calculations.

1817

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT#

Title:

Long-term temperature change of ground heat exchangers

Sponsoring TC/TG/MTG/SSPC:

TC 6.8 Geothermal Heat Pump and Energy Recovery Applications

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

Executive Summary:

Ground-source heat pump (GSHP) systems can achieve high-efficiency by using the relatively low temperature lift between the conditioned space and the ground. GSHP are coupled with ground heat exchangers (GHXs), a network of tubing inserted into the ground by drilling or excavation. An important factor in GHX design is the long-term ground temperature change (i.e. annual non-hysteretic changes in ground temperature caused by unbalanced heating and cooling loads). Existing design methods incorporate a calculation of the long-term temperature change in GHXs, but there is a large uncertainty about how well the calculations reflect installed performance.

Therefore, we propose to conduct analytical and field study of long-term temperature change of ground heat exchangers (GHXs). This long-term temperature change significantly impacts the design length of GHX, so a better understanding of it will reduce design risk, improve system performance, and reduce cost by more accurate sizing. The results of this research project will serve to improve the practice of designing GHXs for all future ground source heat pump systems. Results will be included in future versions of the ASHRAE Applications Handbook Geothermal Energy Utilization chapter and be used to improve the long-term temperature change calculation for GHX designs. Similarly, the results could inform the same design methods in the widely-used ASHRAE publication Geothermal Heating and Cooling. There are also many GHX design software tools used by ASHRAE members, including everything from basic spreadsheets to design software, that could incorporate the findings of this work.

To achieve these results, the research will proceed through the following tasks:

1. Conduct a comprehensive literature review of relevant published and prior knowledge.
2. Identify GHXs for possible field study of long-term ground temperature change.
3. Conduct an uncertainty analysis on the data available for the GHXs identified in task 2.
4. Narrow the list of GHXs from step 2 to those that are likely to achieve reasonable levels of uncertainty.
5. Compile a common database for data from all the GHXs identified in task 4.
6. Analyze data and compare with current methods used in GHX design, specifically with respect to prediction and design incorporating the long-term temperature change. Primarily analytical, and secondarily numerical, methods will be used to evaluate these results in comparison to existing design methods, and suggest improvements to existing methods and literature.
7. Validate existing site measurements at a minimum of three new GSHP installations (newer installations than those from step 4). All data points from step 5 above shall be validated. This last step would lay the foundation for a future study to conduct an even more accurate test of long-term temperature change than this proposed study.

Applicability to the ASHRAE Research Strategic Plan:

These effects are well aligned with several of the goals of ASHRAE research, as outlined in the Research Strategic Plan:

1. *Support development of tools, procedures and methods suitable for designing low energy buildings.*

   GSHPs are a key strategy for achieving low-energy and net-zero buildings. Accurate, cost-effective sizing of GHXs is an important step in implementing more GSHPs.

2. *Support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety.*

   Better understanding of GHX performance will help properly size it to avoid under-sized GHX and resulting poor performance, or expensive oversized GHX.

3. *Maximize the actual operational energy performance of buildings and facilities.*

Appropriate sized GHX will lead to better building performance and more importantly, enable wider adoption of GSHP technology by avoiding oversizing of GHXs.

Application of Results:

The results of this research project will serve to significantly improve the practice of designing GHXs for all future ground source heat pump systems. This will enable more high-performance HVAC systems (like GSHPs) to be installed in the future, and for them to be more efficient and cost effective. These ultimate outcomes will be obtained by applying the results of the research to the tools and references that are used by design engineers to design these systems.

First, the results will be included in future versions of the ASHRAE Applications Handbook Geothermal Energy Utilization chapter, which includes the primary design methods used by engineers to design GHXs. The results could ultimately be used to improve the design method's calculation of long-term ground temperature change. Similarly, the results could inform the same design methods in the widely-used ASHRAE publication Geothermal Heating and Cooling.

There are also design tools, including everything from basic spreadsheets to sophisticated commercial software, that contain these design methods (including long-term temperature change factors). These design tools will likely be updated based on this study.

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 t_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.

Advancement to the State-of-the-Art:

The state-of-the-art design approaches discussed above assume a relatively homogenous, low-porosity substrate. Dynamic moisture change effects are not calculated explicitly (Kavanaugh 2003; Kavanaugh and Rafferty 2014). Adjustments are made but the resulting values represent worst-case scenarios. Ideally, temperature change would include groundwater recharge (vertical flow), groundwater movement (horizontal flow) – which can have a significant impact (Chiasson et al. 2000a), evaporation (and condensation) of water in the soil, and freezing of groundwater in cold climates. Because of these uncertainties, the ASHRAE handbook states: “Because these effects have not been thoroughly studied, the design engineer must establish a range of [GHX] design lengths”. The proposed research would supply data critical to empirically determining the *collective magnitude* of these impacts (if not differentiating between the different impacts).

This research would also lead to improvement in GHX design. The two methods for sizing GHXs discussed above yield significantly different estimations of the long-term temperature change, and therefore the recommended GHX size (Bernier et al. 2008). Some validation of the two sizing methods has been completed, but essentially only at the daily and seasonal timescales. Estimations of GHX performance diverge significantly in the long-term. This research would allow the two design methods to be compared to outcomes observed in installed GHXs.

In short, research is needed to 1) collect long-term GHX data, 2) evaluate existing design methods, 3) identify and understand discrepancies between the outcomes of current design methods.

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/Technical Approach:

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.
        iv. A significant temperature difference (>5ºF) between entering and return temperatures during a significant majority (~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 has already identified a short list of building leads that fit these criteria. The contractor will need to identify additional installations for a successful research project.

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)

<u>Go / No-go decision point:</u> 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 that fit all criteria in 2(a) above and have some level of diversification in siting.
2. The uncertainty analysis needs to show that 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 contractor may be asked to allocate a portion of the remaining budget designing a controlled experiment using a laboratory-like GHX (of which a few exist). The deliverable would simply be a recommended experimental design and measurement parameters.

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

   Continuous data, from first occupancy

   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.
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 comparison. 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.)
   b. 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. ASHRAE RP funding can be used for some nominal fees for this connection to cloud services.
   c. Add other GHXs to that list based on others that have been identified as the research progressed.
   d. Secure agreement from the building owner to participate in the study.
   e. Validate site measurement using separately calibrated sensors for temperature and flow rate.
   f. 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.

<u>Deliverables/Where Results Will Be Published</u>:

Deliverables throughout the project will include the following:

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.

Final Report
A written final report shall be prepared containing complete details of all research, including a summary of the literature review, sites studied, quantitative results, qualitative considerations, and conclusions. The final report will be prepared electronically and hard copies will also be provided.

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.

Science & Technology for the Built Environment or ASHRAE Transactions Technical Papers
One or more papers shall be submitted in a form suitable for publication as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions.

Depending on the nature of the results, we also may request a technical article suitable for publication in the ASHRAE Journal. This would be a voluntary submission and not a Deliverable.

Level of Effort:

Estimated $ Value Range: Total $ 180,000 – 215,000

Duration in Months: 20

Professional-Months, Principal Investigator: 2.5

Professional-Months, Total: 14

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	Contractors understanding of Work Statement as revealed in proposal	15%
2	Quality of methodology proposed for conducting research	30%
3	Qualifications of personnel for this project	25%
4	Student involvement	3%

5	**Probability of meeting the objectives and schedule of the Work Statement**	**27%**

Project Milestones:

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

Authors:

Scott Hackel, Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu, Dennis Koop

References:

ASHRAE HVAC Applications Handbook. Chapter 34. "Geothermal Energy Utilization." ASHRAE, 2015.

Bernier, M.A., A. Chahla, and P. Pinel. 2008. Long-term ground temperature changes in geo-exchange systems. *ASHRAE Transactions* 114(2):342-350.

Carlson, S. 2001. Development of equivalent full load heating and cooling hours for GCHPs applied in various building types and locations. ASHRAE TRP-1120, *Final Report*.

Chiasson, A.D., S.J. Rees, and J.D. Spitler. 2000a. A preliminary assessment of the effects of groundwater flow on closed-loop ground-source heat pump systems. *ASHRAE Transactions* 106(1):380-393.

Cullin, J.R., J.D. Spitler, C. Montagud, F. Ruiz-Calvo, S.J. Rees, S.S. Naicker, P. Konecny, and L.E. Southard. 2015. Validation of vertical ground heat exchanger design methodologies. Science and Technology for the Built Environment 21(2): 137-149.

Kavanaugh, S.P., and J.S. Kavanaugh. 2012. Long-term commercial GSHP performance, part 3. *ASHRAE Journal* 54(9).

Kavanaugh, S.P., and K. Rafferty. 2014. *Geothermal Heating and Cooling: Design of Ground-source Heat Pump Systems*. ASHRAE.

Ruan W., and Horton, W. *Literature Review on the Calculation of Vertical Ground Heat Exchangers for Geothermal Heat Pump Systems*. International High Performance Buildings Conference, Paper 45. 2010.

<u>Other Information for Bidders (Optional)</u>:

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

The process seems well thought out. Its possible that RAC could use a bit more representation from practitioners to balance out the many members with research backgrounds.

But by far the biggest area for improvement in this process is this form. It is antiquated in a variety of ways, including being very difficult to paste information into from the RTAR and other sources. The tabs, formats, justification, etc. all seem off. Perhaps it is a Microsoft Word version issue. But the real improvement would be to shift away form using a process that involves filling in boxes in Word, which is never going to work all that well. A free-form Word document (without boxes), an editable PDF, or even a spreadsheet would work better. Some other type of html or java-based approach may be a solution as well.

Shaping Tomorrow's Built Environment Today

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TO: Chris M Gray, Chair TC 6.8, cmgray@southernco.com
Xiaobing Liu, Research Subcommittee Chair TC 6.8, liux2@ornl.gov
Harvey Sachs, Research Liaison Section 6.0, hsachs@aceee.org

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

DATE: February 10, 2017

SUBJECT: Research Topic Acceptance Request (1817-RTAR), "Long term temperature change of ground heat exchangers"

At their winter meeting, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to conditionally accept it for further development into a work statement (WS) provided that the RAC approval condition(s) below are addressed to the satisfaction of your Research Liaison and incorporated into the WS and/or in a revision to the RTAR.

The following list summarizes the mandatory comments and questions that need to be fully addressed in the updated RTAR and work statement submission:

1. Edit objectives for clarity and include step four from the "Expected Approach" section. Funding levels and duration should be estimated for each step to arrive at a total funding amount and duration for the total project.
2. Need justification for duration and budget.
3. Make it clear the limiting factors such as climate zone, building size or load characteristics, ground heat transfer non-uniformity.

Please coordinate changes to the RTAR with the help of your Research Liaison, Harvey Sachs, hsachs@aceee.org or RL6@ashrae.net. After coordination with your RL send the revised RTAR and/or letter/email of confirmation regarding the modifications agreed on with the RL to MORTS. This response to the approval condition(s) with the RTAR will be posted by ASHRAE as part of the Society's Research Implementation Plan.

After agreement has been reached and the information forwarded to MORTS, develop a work statement with the help of your Research Liaison prior to submitting it to the Manager of Research and Technical Services for consideration by RAC. The work statement must include a cover letter to RAC, detailing how each comment/condition from the RTAR was addressed. The work statement must be approved by the Research Liaison prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers require additional information or rewording for clarification.

The first draft of the work statement should be submitted to RAC no later than December 15, 2018 or it will be dropped from display on the Society's Research Implementation Plan. The topic must be approved for bid by RAC by February 1, 2021 or it will be dropped permanently from plan after four years on plan. The next submission deadline for work statements is May 15, 2017 for consideration at the Society's 2017 annual meeting. The submission deadline after that for work statements is August 15, 2017 for consideration at RAC's 2017 fall meeting.

Project ID	**1817**	
Project Title	**Long term temperature change of ground heat exchangers**	
Sponsoring TC	TC 6.8 (Geothermal Energy Utilization)	
Cost / Duration	$170,000 – 275,000 - 24M	
Submission History	**1st Submission**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2017 Winter Meeting Review		
Essential Criteria	**Voted NO**	**Comments & Suggestions**
Background: The RTAR should describe current state of the art with some level of literature review that documents the importance/magnitude of a problem. References should be provided. If not, then note it in your comments.		***#13*** - Literature review portion. ***#3*** - Adequate references provided.
Research Need: Based on the background provided is the need for additional research clearly identified? If not, then the RTAR should be rejected.		***#3*** - Current bore field design methods seek to limit the maximum entering water temperature to a specified value over a long (~20 year) design period. Except for forensics, there has been little effort to go back and determine systematically the accuracy of the design methods based on current measured state of the bore field.
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject.		***#3*** - Relevance and benefits are adequately described in the RTAR.
IF ABOVE THREE CRITERION ARE NOT <u>ALL</u> SATISFIED - MARK "REJECT" BELOW & CONTINUE REVIEW BELOW		
Other Criteria	**Voted NO**	**Comments & Suggestions**
Project Objectives: Based on the background and need, evaluate whether the project objectives are: 1. Aligned with the need 2. Specific 3. Clear without ambiguity 4. Achievable If not, then appropriate feedback should be provided.	**#6**	***#6*** - 1. There is no need for the literature survey as a separate task. The need and review should be performed when preparing the bid. It can be reported and extended. 2. There is no information on how many instrumented GSHP installations are available for achieving the objectives and how much data available. 3. Are the existing GSHP installations that are instrumented representative for such installations or unique/untypical? Is there an access to data? **#12** - Objectives appear to be the victim of cut and paste errors. By "formations" are the authors referring to geological formations or piping systems? ***#3*** - Good description of project objectives. ***#8*** - Real on-site data would be very valuable, although modeling work also essential and less costly. What climate zones and and what building sizes would this study cover? This should be clearly mentioned in the WS.
Expected Approach and Budget: Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision. Anticipated funding level and duration:	**#6, #12 , #4**	***#6*** - Expensive, why? No justification. 24 months seems quite long. Justification needed. ***#12*** - Each step is clear, but should include an estimate of the anticipated funding and duration. Step four should be listed in the "Project Objective" section. ***#5*** - I understood that to observe the long term conditions of the soil, the comparison of the soil conditions close to the heat exchangers and far from the heat exchangers. It will require considerable labors and moneys. ***#3*** - I will note that the range of 170-275k is somewhat broad. ***#8*** - It is unclear from the present RTAR what key variables will be examined. The site data collection might be limited. Complex factors such as climate, building size and load characteristics, ground heat transfer non-uniformity or non-homogeneous, ground water, etc. Will these be covered by the models? Will new models be developed? How to generalize the results so that the broad ASHRAR membership can benefit from this study?
References: Are the references provided?		
Decision Options	**Initial Decision?**	**Final Approval Conditions**
ACCEPT AS-IS	**#13**	***#12*** - Edit objectives for clarity and include step four from the "Expected Approach" section. Funding levels and duration should be estimated for each step to arrive at a total funding amount and duration for the total project. ***#5*** - More clear and detailed descriptions are required how the research detects the long term condition changes, with less than two years research term. ***#3*** - There is a definite need for this project if GHPs are to achieve a broader market. ***#4*** - Budget shows a pretty big range. Tighten up and consider the scope to get a better handle on this. ***#8*** - Please make it clear the limiting factors such as climate zone, building size or load characteristics, ground heat transfer non-uniformity, etc. Make sure the project will yield generalized results.
ACCEPT W/COMMENTS	**#6, #12 , #5, #4, #8**	
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
ACCEPT W/COMMENTS Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: November 15, 2016

(Please Check to Insure the Following Information is in the RTAR)

A. Title	X
B Executive Summary	X
C. Background	X
D. Research Need	X
E. Project Objectives	X
F. Expected Approach	X
G. Relevance and Benefits to ASHRAE	X
H. Anticipated Funding Level and Duration	X
I. References	X

Title:

Long term temperature change of ground heat exchangers

RTAR # 1817
(To be assigned by MORTS)

Research Classification:

Basic/Applied Research	X
Advanced Concepts	
Technology Transfer	

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

Applications handbook chapter 34
Systems and equipment chapter 9
Geothermal Heating and Cooling (the Blue Book)

Responsible Committee: TC 6.8 Geothermal Energy Utilization

Date of Vote: December 13, 2016

For		13
Against	*	0
Abstaining	*	1
Absent or not returning Ballot	*	2
Total Voting Members		16

RTAR Authors

Lead: Scott Hackel

Others: Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date)

Expected Work Statement Authors

Lead: Scott Hackel

Others: Steve Kavanaugh, Stephen Hamstra, Xiaobing Liu

Potential Co-funders (organization, contact person information):

IGSHPA

Contact: Xiaobing Liu, Liux2@ORNL.gov

	Yes	No
Has an electronic copy been furnished to the MORTS?	X	
Has the Research Liaison reviewed the RTAR?	X	

* Reasons for negative vote(s) and abstentions

Scott Hackel abstained from vote because he was WS author

RTAR # _1817_

Title:

Long term temperature change of ground heat exchangers

Executive Summary

Describe in summary form the proposed research topic, including what is proposed, why this research is important, how it will be conducted, and why ASHRAE should fund it (50 words maximum)

Ground-source heat pumps (GSHPs) are important HVAC tools. We propose to conduct analytical and field study of long term temperature change, because we know too little about their long term temperature performance. This will reduce design risk, improve system performance, and reduce cost by more accurate sizing.

Background

Provide the state of the art with key references (at the end of this document) substantiating it (300 words maximum)

Annually, most commercial GSHP reject more heat to the ground than they extract. Over a decade or less, this can lead to enough heating of the ground to reduce efficiency, but the controlling variables are poorly understood. Ground heat exchanger (GHX) design methods that are widely used do attempt to account for this long-term temperature change. However, the impact of heat induced moisture migration, groundwater flow, and phase change has 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. Likewise, the impact of moisture freezing in cold climate applications has not been widely addressed in the design of vertical heat exchangers.

Two general GHX sizing approaches are recognized in the ASHRAE 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 t_p to the design entering fluid temperature. A table of t_p values is given in the handbook. The other common approach given in the handbook for sizing GHXs uses g-functions (ASHRAE, 2015). With this method, thermal interference among boreholes is implicitly accounted for and t_p is eliminated. More complex software tools are required to implement this approach.

Neither has been adequately verified, but Kavanaugh and Kavanaugh (2012) examined ground heat exchanger performance in 40 commercial buildings with vertical ground heat exchangers and between 5 and 25 years of operation. The data collected was limited to approach temperatures and other somewhat static data and was not able to be compared to either of the design methods or long-term temperature change predictions discussed above.

Research Need

Use the state of the art described above as a basis to specify the need for the proposed effort (250 words maximum)

These design approaches assume a relatively homogenous, low-porosity substrate. Dynamic moisture change effects are not calculated explicitly (Kavanaugh 2003; Kavanaugh and Rafferty 2014). Adjustments are made but the resulting values represent worst-case scenarios. Ideally, temperature change would include groundwater recharge (vertical flow), groundwater movement (horizontal flow) – which can have a significant impact (Chiasson et al. 2000a), evaporation (and condensation) of water in the soil, and freezing of groundwater in cold climates. As a result of these uncertainties, the ASHRAE handbook states: “Because these effects have not been thoroughly studied, the design engineer must establish a range of [loop] design lengths”.

Compensating for the uncertainty of long term temperature change affects GSHP system design. For example, Ruan (2010) estimated that 10-30% of vertical GHXs are oversized. In other scenarios, it is possible this issue is leading to GHX that are too small; compromising comfort and dependability.

More importantly, these two methods for sizing GHXs yield significantly different answers for the long term temperature change, and therefore the recommended GHX size (Bernier et al. 2008). Some validation of the two sizing methods has been completed, but essentially only at the daily and seasonal timescales. Different models diverge significantly in the long term and there is little long-term data available to which models can be compared.

In short, research is needed to 1) collect long-term GHX data, 2) validate existing design methods, 3) identify and understand discrepancies between design methods.

Project Objectives

Based on the identified research need(s), specify the objectives of the solicited effort that will address all or part of these needs (150 words maximum)

In order to alleviate the gaps in knowledge described above, we propose primary research be conducted to provide data and validate 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: of collecting these data would be to:

- Test the accuracy of the current long term temperature change methods against field data from actual GHXs.
- Develop improvements to the methodologies. Provide information needed to improve the accuracy especially by developing descriptions/characteristics of formations that contribute to or mitigate long term temperature change.

Expected Approach _Needs to be reworked

Describe in a manner that may be used for assessment of project viability, cost, and duration, the approach that is expected to achieve the proposed objectives (200 words maximum).

Check all that apply: Lab testing [X] Computations,( ) Surveys,[X] Field tests,[X] Analyses and modeling, [ ] Validation effort [ ] Other (specify) ( )

These check boxes do not work with the current version of Word. The following apply and should've been checked: Computations, Field tests, and Analyses and modeling.

The following approach could be used to achieve the objectives.

1. A literature review should be conducted. In addition to understanding the state of the art in more detail, the review would help to understand which type of thermal phenomena are not fully captured in current sizing algorithms.
2. The project would continue by comparing predictions of long-term temperature change to validated monitored data from actual GHXs in the field. There are a significant number of well-instrumented GSHP systems in operation that TC 6.8 is aware of. Data may be needed from building automation systems, local geology and hydrogeology, and thermal conductivity tests.
3. Suggest improvements to the methodologies. Provide information needed to improve the accuracy especially by developing descriptions/characteristics of formations that contribute to or mitigate long term temperature change.
4. A final step would attempt to validate existing site measurements at at least two new GSHP installations. Operators of these two sites would be instructed to track performance and any changes in operation over time. This third step would lay the foundation for a future study to conduct an even more accurate test of long-term temperature change than this proposed study.

Relevance and Benefits to ASHRAE

Describe why this effort is of specific interest to ASHRAE, its impact, and how it will benefit ASHRAE and the society. How does it align with ASHRAE Strategic Plans and Initiatives? How does it advance the state of the art in this area in general? Are there other stakeholders that should be approached to obtain relevant information or co-funding? (350 words maximum)

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, which will likely reduce the size, and therefore the cost, of a typical GSHP system. This will in turn allow more GSHPs to be deployed.

These effects are well aligned with several of the goals of ASHRAE research.

1. *Support development of tools, procedures and methods suitable for designing low energy buildings.*

   GSHPs are a key strategy for achieving low energy buildings, especially net zero ones. Accurate, cost-effective sizing of GHXs is an important step in implementing more GSHPs.

2. *Support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety.*

   Better understanding of GHX performance will help properly size it to avoid under-sized GHX and resulting poor performance, or expensive oversized GHX.

3. *Maximize the actual operational energy performance of buildings and facilities.*

   Appropriate sized GHX will lead to better building performance and more importantly, enable wider adoption of GSHP technology by avoiding oversizing of GHXs.

Additionally, ASHRAE members will appreciate the more accurate sizing algorithms. 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. As would the handbook chapter on geothermal utilization.

Anticipated Funding Level and Duration

Funding Amount Range: $ 170,000 – 275,000

Duration in Months: 24

References

List the key references cited in this RTAR

ASHRAE HVAC Applications Handbook. Chapter 34. "Geothermal Energy Utilization." ASHRAE, 2015.

Bernier, M.A., A. Chahla, and P. Pinel. 2008. Long-term ground temperature changes in geo-exchange systems. *ASHRAE Transactions* 114(2):342-350.

Carlson, S. 2001. Development of equivalent full load heating and cooling hours for GCHPs applied in various building types and locations. ASHRAE TRP-1120, *Final Report*.

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Kavanaugh, S.P., and J.S. Kavanaugh. 2012. Long-term commercial GSHP performance, part 3. *ASHRAE Journal* 54(9).

Kavanaugh, S.P., and K. Rafferty. 2014. *Geothermal Heating and Cooling: Design of Ground-source Heat Pump Systems*. ASHRAE.

Ruan W., and Horton, W. *Literature Review on the Calculation of Vertical Ground Heat Exchangers for Geothermal Heat Pump Systems*. International High Performance Buildings Conference, Paper 45. 2010.

Feedback to RAC and Suggested Improvements to RTAR Process

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I would recommend updating this form. A couple of the features did not work on my version of Word; I ended up recreating pieces of the document.