1. The Research Project Statement: Effectiveness of Ground Source Heat Pumps - Probabilistic Approach

1.1 Background:

Ground source heat pumps (GSHP) are electrically powered systems that tap the stored energy of the greatest solar collector in existence: the earth. These systems use the earth's relatively constant temperature to provide heating, cooling, and hot water for homes and commercial buildings.

As commercial applications are increasing (SPITLER, JD, 2005), research is driven by the following areas:

- System simulation – computer simulation of GSHP systems with respect to energy calculations provides estimates for operating costs to support decision-making. Development of ground-loop heat exchanger models (PAHUD, 1996, YAVUZTURK, 1999a) facilitates both energy calculation and investigation of various design options. Summary of available analytical and numerical simulation approaches is available e.g. in YAVUZTURK (1999b).

- Commercial buildings are often cooling dominant. More heat is injected into ground due to cooling than extracted due to warming. The net imbalance of heat rejected to the ground each year can result in long-term temperature rise of the loop and, consequently reduced performance of heat pumps. This may be mitigated during the design process by increasing the size of the ground loop heat exchanger or alternatively by alternative a heat rejection mechanism such as a cooling tower, water heating or snow melting (CHIASSON, 2000).

- Heat exchanger sizes and initial costs have been reduced due to research in optimization of the ground heat transfer. The ground heat transfer was improved by increasing ground thermal conductivity (REMUND, 1999, ALLAN, 1999) and better borehole design (HELLSTRÖM, 2000).

- Development of in situ measurement techniques with reduced uncertainty (AUSTIN, 2000, EKLÖF, 1996, GEHLIN, 2003) for ground thermal conductivity. Reduction of uncertainty is significant because the overly conservative estimate of the ground thermal conductivity may result in a larger ground-loop heat exchanger than needed with the unnecessary excess costs in the order of tens of thousands of dollars (SPITLER, JD, 2005).

A suitable system is designed in order to maintain internal temperature conditions according to client demand. Current evaluation of the ground source heat pump cooling and heating capability for the buildings is based on the deterministic evaluation of the performance in case of extreme summer and winter temperatures. The system is frequently designed to meet the most demanding conditions. Those most demanding conditions can be rare, though. The long-term ground heat change effecting the heating or cooling dominated building requires knowledge of the sequence of temperatures. The temperature sequences are obtained from a typical meteorological year or from actual weather data (PERTZBORN, 2011). Some simulations do not take the temperature history into account (KAVANAUGH, 1999).

Any GSHP system is subject to a range of conditions and properties that are uncertain in nature. These include:

- The building heating and cooling loads, due to uncertainties in building thermal properties, quality of construction, occupancy, etc. and due to uncertainties in future weather.

- The ground thermal properties, including variations due to changes in moisture content in the unsaturated region and the depth of the water table. Also, the ground is not homogeneous and properties may vary over the borehole field.

- Groundwater flow effects that are usually small.
Borehole completion - drilling conditions often lead to variations in down-hole diameter; U-tube placement is usually not controlled.

Performance of the heat pump and circulating pumps can vary from unit-to-unit and with time, due to fouling.

The degree to which physical reality conforms to assumptions in the model, many of which are necessary to achieve an acceptable computation time for design purposes.

Probabilistic simulation can address the variation in input parameters such as the ambient temperature and the borehole conductivity. There is range where the input parameters are probable (e.g. ESEN, 2009, FREEDMAN, 2012). It would be valuable for the temperature, borehole diameters and the soil characteristics using the statistical methods, and would allow the customer to know the chance that the heat-pump system will not be able to maintain given temperature in the building. The probability that the system can heat or cool the building to the desired range can be estimated using the probabilistic assessment (MAREK, 1995, MELCHERS, 1999, MAREK, 2003). The correlation between random input characteristics can be statistically described as well. The suitable probabilistic approach in case of time-dependent parameters such as temperature and snowfall can be well described by time pulses (see e.g. SÝKORA, 2005) or load-duration curve MAREK (1995). Load duration curve is a sorted history of loading formed as a frequency histogram.

Temperature is a time-dependent parameter and can be treated as a probabilistic distribution – histogram. Such an approach, called “Load duration curve” for time-dependent structural loading, was adopted by MAREK et al. (1995). This load duration curve can be transformed to a frequency histogram that can be used as an input for probabilistic analysis using e.g. Monte Carlo simulation. Such simulation was used in the Simulation-based Reliability Assessment method (MAREK et al., 1995, 2003) in case of structural safety problems MAREK (1995, 2003) or e.g. KONEČNÝ (2002). The durability of reinforced concrete structures (KONEČNÝ, et al. 2007) was solved using the Simulation-based Reliability Assessment method (SBRA) and Finite elements analysis. The wind load duration curve evaluation was used in the estimation of windmill energy outcome estimation using SBRA (KONEČNÝ, 2004). The possibility of non-normal correlated random input variables was studied in (VOŘECHOVSKÝ, 2003, PHOON, 2004, VOŘECHOVSKÝ, 2009).

The drawback of probabilistic assessment caused by its complexity is the high demand on both sides of computer time, as well as for the time of the practicing engineer. The reason is caused by the necessity to describe randomness of input parameters and to perform the analysis, in case of Monte Carlo, for thousands of times. Finite element analysis with a set of approximately 2000 linear equations for the solution of a durability problem related to chloride diffusion took 24 hours of quad-core computer station time (KONEČNÝ, et al. 2007). Reduction of the computer burden can be done using stratified sophisticated Monte Carlo approaches such as Latin Hypercube Sampling VOŘECHOVSKÝ (2009) or Importance sampling (SCHUÉLLER, 2002, PRAKS, 2002).

1.2 Objectives:

The aim of the project is to evaluate suitability of probabilistic performance-based assessment of the building ground source heat-pump heating and cooling system with respect to:

- Effect of variation of ground soil parameters under extreme temperature conditions
- Effect of variation of ground soil parameters with time-dependent simulation with the typical-year temperature data
- Effect of the random variation of temperature based on the load duration curves compared to the typical-year temperature data

Probabilistic analysis of the ground source heat pump capability to maintain the requested temperature in the buildings included will be based on the numerical estimation of the heat pump power outcome, and building energy losses and gains. The heat cooling and heating system model will include the ground source heat pump, soil conditions, the building and the ambient temperature.

The performance of the heating/cooling system will be evaluated based on its capability to maintain the indoor temperature in the building within a defined range. The procedure to compute building heat losses and gains can be computed according to principles contained in e.g. ČSN 06 0210 or the U.S. equivalent. The ability of the system to maintain the requested indoor climate will be quantified using probability. The probabilistic performance assessment will be conducted using suitable probabilistic tool e.g. Monte Carlo simulation adopted in the SBRA method (MAREK, 1995).
The input parameters that are random in nature, such as thermal conductivity of the borehole (BEIER, 2011, FREEDMAN, 2012), will be described by statistical means.

The majority of the variable parameters are ambient temperature, borehole and ground parameters. The description of ambient temperature will be prepared based on the climate data time series in the form of typical-year temperature load duration curve (MAREK, 1995). The ground parameters that can have significant variation are temperature, thermal capacity and thermal conduction. Statistical relationship between soil input parameters can be addressed using correlation (PHOON, 2004, KONEČNÝ, 2007, VOŘECHOVSKÝ, 2009).

The research will consists of a case study of a typical building with a ground heat pump heating and cooling system conducted for several alternatives. The alternatives will differ in the ability to maintain indoor temperature in the requested range. The result of the study will be the expenditure of the respective alternative versus its reliability, quantified in terms of probability. The suitability of the probabilistic approach application will be discussed.

The research will yield: (a) Selection of suitable approach for the probabilistic model of the GSHP system, (b) A case study of a typical building with a ground heat pump heating and cooling system conducted for several alternatives, (c) Discussion about the suitability of the probabilistic approach application for the GSHP system modelling.

1.3 Significance:

Probabilistic analysis can give an idea of the probability that the system does not meet the given thermal criteria. It can address the influence of variability in input parameters, especially temperature and subsoil parameters.

Probabilistic assessment of ground source heat pump cooling and heating capability for the buildings can be a tool for sound decision if the increased investment is paid off by better system performance. Evaluation of the probabilistic simulation effectiveness and feasibility on the selected examples can bring light on to its advances and drawbacks in case of GSHP applications. The question is whether probabilistic assessment is a suitable tool for the assessment with respect to its complexity and time demand on both computer use as well as of the engineer.

Better estimation of the necessary heat pump energy input can save money of clients allowing selection of the most suitable system with an acceptable risk of not meeting the desired performance. Application of probabilistic assessment to other fields gives the applicant the possibility of inter-disciplinary outreach and opens new horizons.

This research can be one of the starting points for the development of research collaboration between the College of Engineering, Architecture & Technology at Oklahoma State University (CEAT OSU) and VŠB-Technical University of Ostrava (VŠB-TUO). VŠB-TUO is conducting research in the power engineering including ground source heat pumps as well. Energy related research is conducted in various departments of the VŠB-TU Ostrava including Faculty of Civil engineering and research center “Energy Units for Utilization of non Traditional Energy Sources” (ENET research center) of VŠB-TU Ostrava. The initial meeting between representatives of CEAT OSU and ENET happened in November 2012. The state of the art research and knowledge of the U.S. colleagues in the Ground Source Heat Pump Association can be valuable for the research and development at VŠB-Technical University of Ostrava.

The one year internship in the U.S.A. can play a significant role in the curriculum development of the applicant, especially with respect to the influence of a high quality research university such as Oklahoma State. The cooperation with U.S. colleagues can lead to preparation of quality research and the subsequent publication in peer-reviewed journals. Such research devotion and publication possibilities would be very hard to achieve under current conditions and obligations at the home institution.

These publications are essential with respect to personal career development as well as in the processes evaluation of the VŠB-TUO as well as study programs at the Faculty of Civil Engineering, VŠB-TUO.

1.4 Evaluation and Dissemination:

The procedure of probabilistic performance-based assessment of the building ground source heat pump heating and cooling system can be used in the Czech Republic as well. The assessment procedure can be further utilized into other heat sources such as solar systems or conventional heat source systems, and programmed at VŠB-TUO in the form of a stand-alone program that can be used by the broader community. This program can join structural analysis tools as well as reliability analysis tools already available (BROŽOVSKÝ, JANAS).

The result of the research will be presented at VŠB-Technical University of Ostrava by the form of lectures for the Faculty as well as a broader audience. Sample examples would be a very good topic for the practices of the class
“Reliability and Safety of Buildings” for the students of the Building Environment study branch at the Civil Engineering Faculty of VŠB-TUO.

The results of research will be proposed for publication in a suitable journal such as “Energy and Buildings”.

Research and the residence in the United States is necessary because the research will be conducted in collaboration with the International Ground Source Heat Pump Association (IGSHPA) that is based at Oklahoma State University. IGSHPA utilizes state-of-the-art facilities for conducting GSHP system installation training and geothermal research. IGSHPA’s most current advancements in the geothermal industry is significant with respect to the given project objective. The most current advancements of CEAT OSU in the geothermal industry is significant with respect to the given project objective as can be seen in bibliography of authors (BEIER, 2011, YAVUZTURK, 1999a, 1999b, CHIASSON, 2000, 2009a, 2009b, AUSTIN, 2000, GEHLIN, 2003, FISHER, SPITLER, 2005, 2011, 2006, UNDERWOOD, 2007, CULLIN, 2010, 2011, XING, 2011).

1.5 Duration:

Project can be completed within a ten month period. It will be completed in the following steps:

March 2013 – June 2013 (In Czech Republic):
- Familiarization with the state-of-the-art literature about Ground Source Heat Pump at CEAT OSU
- Preparation of the temperature Load duration curve simulation procedure

August 2013 – September 2013:
- Preparation of the building thermal balance model with respect to probabilistic simulation
- Selection and preparation of the Ground Source Heat Pump energy output model with respect to probabilistic simulation (analytical, numerical transient, response factor method, YAVUZTURK, 1999b)

October 2013 – November 2014:
- Integration of the Heat pump model and the building thermal balance model
- Preparation of the probabilistic building thermal balance model including random variable temperature
- Case study I - Effect of variation of ground soil parameters under extreme temperature conditions

December 2013 – January 2014:
- Case study II - Effect of variation of ground soil parameters with time-dependent simulation with the typical-year temperature data
- Case study III - Effect of random variation of temperature based on the load duration curves compared to the typical-year temperature data

February 2014 – March 2014:
- Case study IV – Effect of heat pump loop length on the thermal balance of the typical building with a GSHP
- Preparation of the publication
- Finalization and completion

1.6 English Proficiency:

Applicant can easily understand, verbally communicate and write in English, while daily use will significantly improve grammar and phrasing.

2. Teaching Proposal:

Reliability in Engineering

2.1 Teaching Experience:

The teaching experience started in 2002 in the Reliability of Structure class. Since the fall of 2006, the Applicant has assisted in practices of the following undergraduate subjects from the portfolio of the Department of Structural Mechanics at the Faculty of Civil Engineering, VŠB-Technical University of Ostrava.
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- Statics  
- Advanced Statics I and II  
- Elasticity of Materials  
- Reliability of Structures  
- Basics of Finite Element Analysis.

From spring 2011, the Applicant has lectured on:

- Statics  
- Finite Element Analysis (graduate level).

The Applicant has prepared the topics for the practices from the subject Reliability of Structures and the Basics of Finite Element Analysis. The teaching methods applied were Lecture × Practice. Students were familiarized with theory through attendance to lectures, and the acquired knowledge was practiced. In Reliability of Structures class, each student prepared a project with his/her own probabilistic assessment of the selected problem. Student project had to be documented and defended.

Through research in the field of probabilistic reliability assessment and experience with Reliability of Structures practices, preparation and assistantship, the Applicant obtained a good understanding of the problem, allowing him to teach Reliability in Engineering.

Current teaching experience is based on presenting students facts or principles. Students then apply the principles on given examples according to presented models. There is a lack of interaction between students and teacher in such a system. In some practices, there are student case studies that are to be presented and discussed in the class. The discussion is generally not vital.

2.2 Proposed Teaching:

Applicant proposes to teach the subject Reliability in Engineering that would introduce the students to an understanding of the role of randomness and probability in engineering tasks.

Students would become familiar with the probabilistic calculations through selected engineering tasks such as the scatter of steel yield strength, beam bending resistance, durability of reinforced concrete bridge deck exposed to chlorides, thermal balance of building, and water balance in the reservoir of rain water. Students can understand the role of scatter of input parameters in the solution of engineering tasks. They became familiar with the methods of the simulation-based probability evaluation, and the advantages and drawbacks in the case of the application of probabilistic calculus.

The typical problems discussed in each class will be prepared as on-line material suitable for distance learning. The practice will evaluate the home-based preparation and gives the students the possibility of interaction and learning through sharing.

2.3 English Proficiency:

Please find the requested information in part 1.6 English Proficiency.

2.4 Expected Outcomes:

Even a small amount of teaching in the U.S.A. would be a very valuable experience given student-teacher interaction. Acquiring and practicing of the know-how of the modern, on-line learning that is available at CEAT OSU will be vital for the development of VŠB-TU Ostrava as modern university in the 21st century.

The Applicant would like to emphasize the current conditions at the Faculty of Civil Engineering at VŠB-TU Ostrava, which are a modern and strict study program dominated by compulsory subjects. Importance is given to learning facts or understanding a problem. The quality of the understanding is evaluated based on tests or oral exams. Students can attend lectures with theory and compulsory attends practices where are the knowledge and skills tested.

A better understanding of the systemic differences of U.S. universities, with an emphasis on the connection of freedom of choice and responsibility, can help the Applicant as well as others given his position in the Academic Senate. Such experience is important given the continued transformation of VŠB-TUO towards a modern, research-based university.