EXTENSION OF EXISTING DESIGN AND SIMULATION MODELS

Jeffrey D. Spitler Ph.D., P.E., Andrew D. Chiasson, Cenk Yavuzturk

Oklahoma State University
School of Mechanical and Aerospace Engineering
Stillwater, OK

KEY WORDS

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PROJECT BACKGROUND AND STATUS

This project originated in 1996 with the aim to reduce the first costs of closed-loop ground-source heat pump systems by reducing the necessary size of the ground loop heat exchanger (i.e. the borehole depth). Commercial buildings are generally cooling-dominated, and therefore reject more heat than they extract over the annual cycle. For applications such as convenience stores and restaurants, auxiliary loads such as that from refrigeration systems and icemakers significantly add to the amount of heat rejected to the ground. In order to dissipate the heat, the required ground-loop heat exchanger length may be as much as double the required length if the annual loads were balanced. Consequently, under these circumstances, ground-source heat pump systems are often eliminated from consideration during the feasibility study phase of the HVAC design process because of excessive first cost.

To effectively balance the ground loads and reduce the necessary size of the ground loop heat exchanger, supplemental components have been integrated into the ground-loop heat exchanger design. In applications where the excess heat that would otherwise build up in the ground is useful, domestic hot water heaters, car washes, and pavement heating systems can be used. In cases where the excess heat cannot be used beneficially, shallow ponds can provide a cost-effective means to balance the thermal loading to the ground and reduce heat exchanger length.

Development and testing of design and simulation models are on-going as part of this project. During FY98, several component models were developed for use with TRNSYS, a transient system simulation program with a modular structure. A short-time step ground-loop heat exchanger model (Yavuzturk and Spitler, 1999) and a heat pump model are the core components in the simulated systems. Supplemental heat rejecter component models developed during FY98 include a pavement heating model and a pond model. Field data from heat rejection subsystems have been collected at Oklahoma State University during FY98 and will be used to validate the component models during FY99. Other models currently under development include an icemaker model, a refrigeration system model, and a heat pump model with domestic hot water heating capability.

PROJECT OBJECTIVES

The overall objective of this project is to develop component models of supplemental heat rejecters and auxiliary equipment that may be connected to the ground loop heat exchanger. It may be advantageous for the building owner to connect auxiliary equipment to the loop, and in many cases this may also reduce the size of the ground loop heat exchanger, and hence the first cost.

Technical Objectives

- Develop component models of supplemental heat rejecters, specifically pavement heating systems and shallow ponds.

- Develop models for design and simulation of auxiliary load components such as icemakers, refrigeration systems, domestic hot water heaters, etc..

Expected Outcomes

- Availability of component models and simulation tools which can predict performance of a system with auxiliary equipment and/or supplemental heat rejecters will facilitate design and installation of such systems. The use of supplemental heat rejecters may reduce the size of the ground heat exchanger significantly.

APPROACH

Models capable of simulating ground-source heat pump systems and auxiliary components on an hourly or minutely basis have been developed in the TRNSYS modeling environment:

- <u>Ground-loop heat exchanger model:</u> Yavuzturk and Spitler (1999) describe the basis and use of this model. It is based on non-dimensional short time-step temperature response factors as an extension of the long time-step response factors as provided by Eskilson (1987). The short time-step response is based on an analytically validated, transient two-dimensional implicit finite volume model that simulates the heat transfer over a vertical U-tube ground heat exchanger as developed by Yavuzturk et al. (1999).

- <u>Heat pump model:</u> This component model simulates the performance of a simple heat pump. Inputs to the model include sensible and latent loads, entering fluid temperature, and fluid mass flow rate. It is used with pre-calculated building loads that are read from an external file. The model uses quadratic curve-fit equations of manufacturer’s catalog data to compute the heat of rejection in cooling mode, heat of absorption in heating mode, and the heat pump power consumption. Outputs provided by the model include exiting fluid temperature, power consumption, and fluid mass flow rate. Development of a more detailed heat pump model is currently in progress.

- Pavement Heating Model: This component model simulates heat transfer within and to/from a hydronically-heated pavement slab. Conduction in the model is treated as two-dimensional and transient, and is solved using the finite difference method. The fluid is assumed to be carried by a series of pipes positioned in parallel circuits, which are embedded in the slab. Environmental heat transfer mechanisms simulated by the model include solar radiation heat gain, convection heat transfer to the atmosphere, thermal or long-wave radiation heat transfer, sensible heat transfer to snow, heat of fusion required to melt snow, and heat of evaporation lost to evaporating rain or melted snow. Heat transfer mechanisms within the pavement slab include conduction through the pavement material and convection due to flow of the heat transfer fluid through the embedded pipes. Outputs provided by the model include pavement surface temperature, exiting fluid temperature, and heat rejected to the slab.

- Pond Model: This component model computes the bulk temperature of a surface water body. The model accounts for several natural heat transfer mechanisms within the surface water body plus convective heat transfer due to the closed-loop heat exchanger coil. The heat transfer fluid is assumed to be carried by a series of pipes in the form of bundles or "slinky" coils. Environmental heat transfer mechanisms that are simulated by the model include solar radiation heat gain, convection heat transfer to the atmosphere, thermal or long-wave radiation heat transfer, conduction heat transfer to the surrounding soil or fill material, ground water discharge contributions, and mass transfer due to evaporation. The conceptual model is translated into a mathematical model using a lumped-parameter (or lumped-capacitance) approach; therefore, temperature gradients are assumed to be negligible. The resulting differential equation describing the overall energy balance on the pond is solved analytically. Some outputs provided by the model include average pond temperature, exiting fluid temperature, and heat rejected to the pond.

RESEARCH RESULTS

At this stage of this project, the currently developed models can be used as preliminary design tools for "order-of-magnitude" cost comparison of alternatives. Upon further validation and refinement of the component models, more detailed cost comparisons can be made.

An example application is provided using an actual building located in downtown Tulsa, Oklahoma that represents a cooling dominated commercial building. It is a four-story, 45,000-ft^2 (4182 m^2) office building, with a peak load of approximately 100 tons (352 kW). The modeled borehole loop field consists of 100 boreholes, each 250 ft. (76.2 m) deep, arranged in a 10 X 10 rectangular configuration and spaced 25 ft. (7.6 m).

The average borehole fluid temperature for the first three years of operation is shown in Figure 1. As shown in Figure 1, the average borehole fluid temperature increases by about 10 °F (5.6 °C) per year, resulting in the fluid temperature to exceed the heat pump's maximum allowable entering fluid temperature. From a design perspective, there are two choices: (1) the ground loop heat exchanger needs to be increased by 110% from its already relatively large size or (2) supplemental heat rejection components could be used to avoid long-term thermal build-up in the ground.

Figure 2 shows the average borehole fluid temperature when a 68 car, 21,600 ft^2 (2025 m^2) parking lot heating system is added and Figure 3 shows the average borehole fluid temperature when a 5400 ft^2 (444 m^2) pond is added to the system. For these simulations, the heat exchange fluid was diverted to the heat rejecter component (the pavement or the pond) when the fluid exiting the heat pump exceeded the pavement (or pond) temperature by 10 ^{o}F or more. The result is that the maximum heat pump entering fluid temperature for each year has leveled off to an acceptable value. The designer can vary input data such as pavement (or pond) area or control strategy in order to achieve design goals.

FUTURE PLANS

- Development of a detailed heat pump model with a desuperheater option.
- Development of an icemaker model and a refrigeration system model.
- Validation of the pond model and the pavement heating model with field-collected data.
- Parametric studies with various system control and operating strategies to investigate and compare potential cost savings.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Organization	***Type and Extent of Interest***
Geothermal Design and Engineering	Modeling of auxiliary components, and accounting. for auxiliary equipment in GLHE design
Air-O Heat and Air Conditioning	Use of shallow heat rejecters.
Phillips and Bacon (Consulting Eng.)	Reduction of ground loop heat exchanger size.

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CONTACTS

Lew W. Pratsch
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585
V:(202) 586-1512 Fax: (202) 586-8185
e-mail: LEW.PRATSCH@hq.doe.gov

Jeffrey D. Spitler, Ph.D., P.E.
Associate Professor
School of Mechanical and Aerospace Engineering
Oklahoma State University
218 Engineering North
Stillwater, OK 74078
V:(405)744-5900 Fax:(405)744-7873
e-mail: spitler@okstate.edu

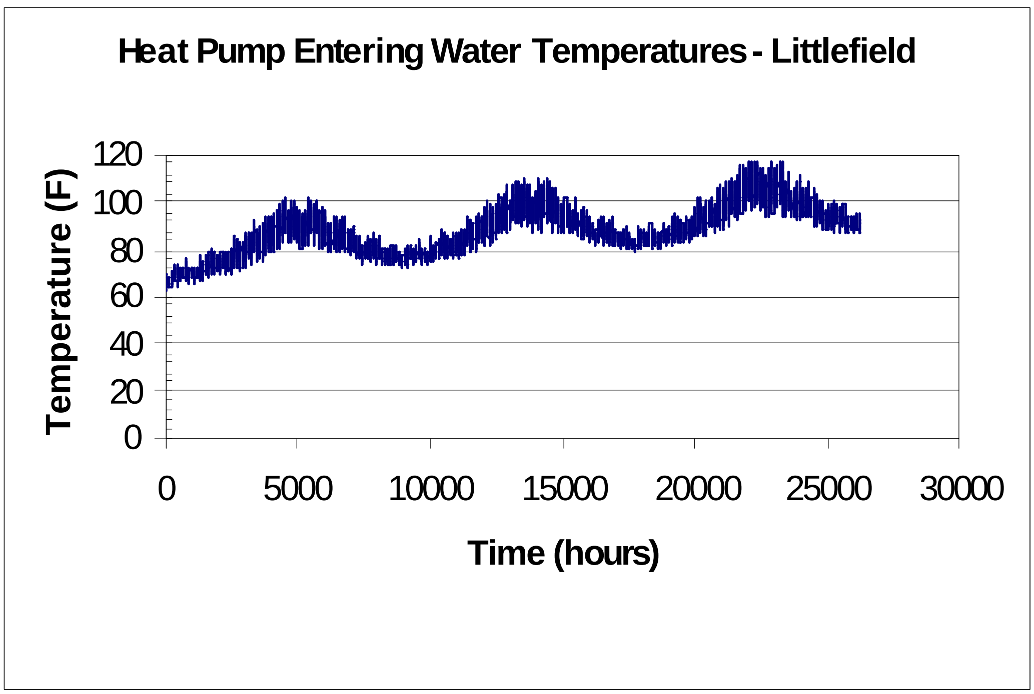

Figure 1. Increase in the heat pump entering water temperature without supplemental heat rejecters.

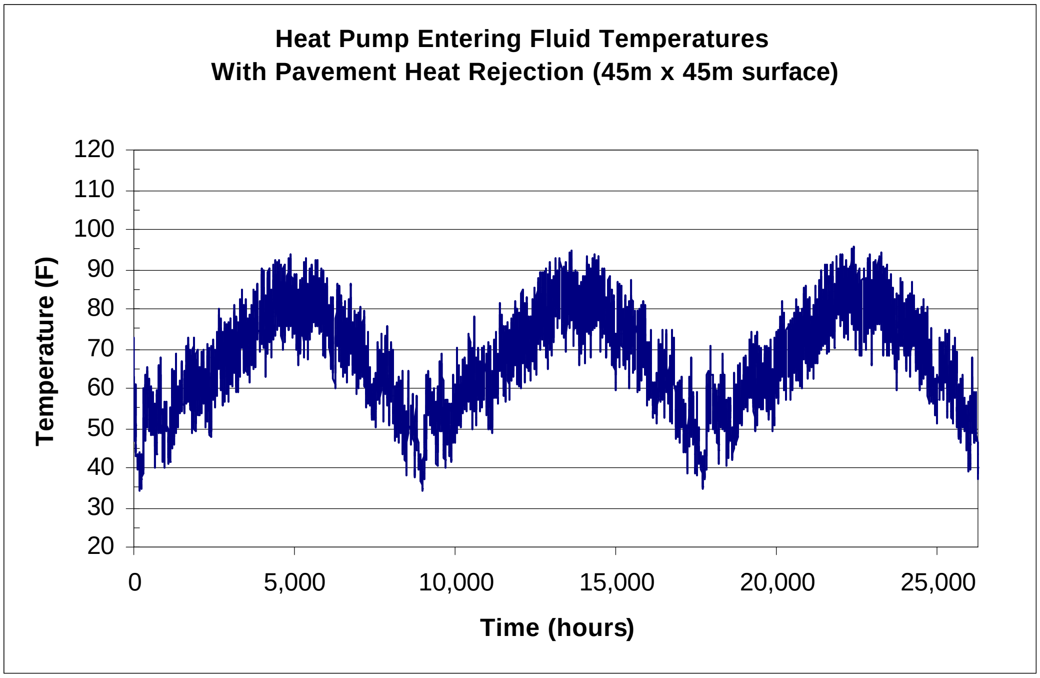

Figure 2. The heat pump entering water temperature with the pavement-heating model.

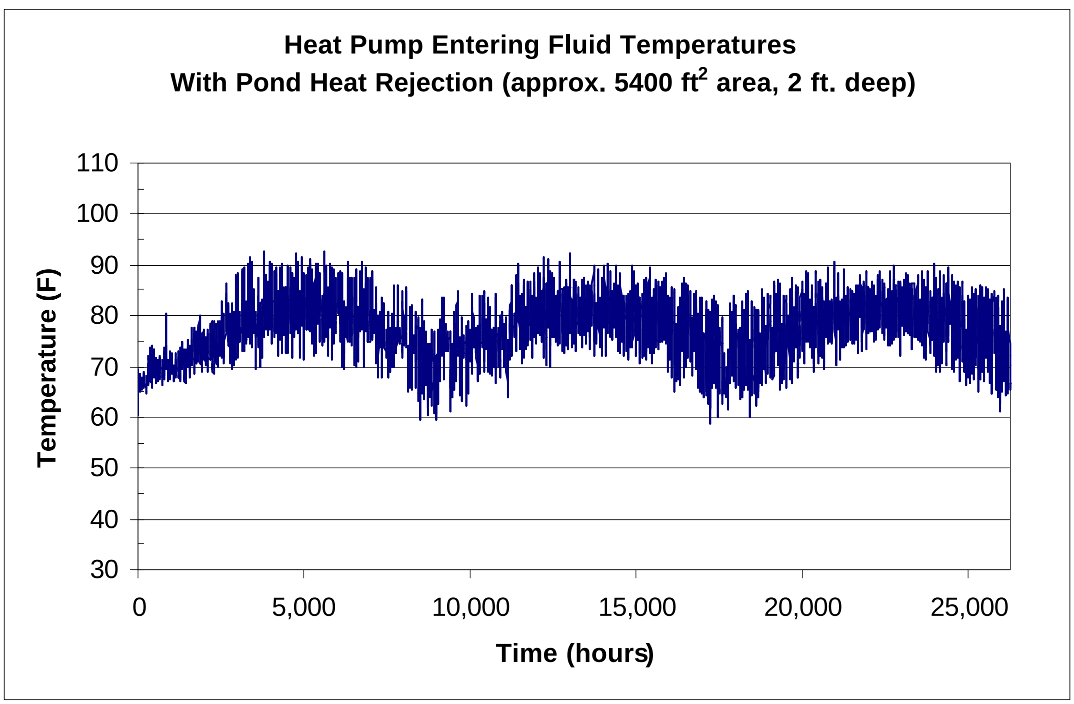

Figure 3. The heat pump entering water temperature with the pond model.