EXTENSION OF EXISTING DESIGN AND SIMULATION MODELS

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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 (GSHP) systems by reducing the necessary size of the ground loop heat exchanger (GLHE). 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 GLHE length may be as much as double the required length if the annual loads were balanced. Consequently, under these circumstances, GSHP 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 GLHE, supplemental components have been integrated into the system 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 GLHE length. GSHP systems that use a supplemental heat rejecter have become commonly referred to as "hybrid GSHP systems".

Development and testing of design and simulation models were conducted during FY98. Several component models were developed for use with TRNSYS and HVACSim+, which are transient system simulation programs with a modular structure. A short-time step GLHE model (Yavuzturk and Spitler, 1999) and a simple water-to air heat pump model are the core components in the simulated systems. Supplemental heat rejecter component models have been developed during FY98 and were validated during FY99 using field data collected from experimental setups at Oklahoma State University. These include a pavement heating model (Chiasson, et al., 2000a) and a pond model (Chiasson et al., 2000b). A detailed water-to-water heat pump model (Jin and Spitler, 2000) was also developed during FY99 and was validated using manufacturer's catalog data. Additionally, a comparative study was conducted to investigate the impacts of various operating and control strategies for a hybrid GSHP application using a cooling tower (Yavuzturk and Spitler, 2000). The work of Yavuzturk and Spitler (2000) was extended by Ramamoorthy et al. (2000) to optimally size a hybrid GSHP that uses a cooling pond as a supplemental heat rejecter.

PROJECT OBJECTIVES

The overall objective of this project was to develop and validate component models of supplemental heat rejecters and auxiliary equipment that may be connected to the GLHE, and to investigate the design of hybrid GSHP systems. There is a trade-off between the size of the ground loop heat exchanger, the size of the supplemental heat rejecter, and the control strategy used to operate the supplemental heat rejecter. Having this many degrees of freedom adds some difficulty to the design process.

Technical Objectives

- Validate the pond model and the pavement heating model with field-collected data.
- Develop a detailed water-water heat pump model based on laws of thermodynamics.
- Investigate the impact of various control and operating strategies of hybrid GSHPs to determine potential cost savings.

Expected Outcomes

- Availability of component models and simulation tools that can predict performance of hybrid GSHP systems, which have the potential to reduce the size of the GLHE significantly. These tools will facilitate the design and installation of such systems.

APPROACH

Validation of Existing Models

<u>Pavement Heating Model Validation:</u> Details of this model and the model validation results are described by Chiasson et al. (2000a). A concrete test slab was constructed at Oklahoma State University and was used for this study. The test slab is rectangular with a plan area of 40 ft by 4 ft and a thickness of 6 in. The slab is underlain by 6 in. of sand fill. Heat was rejected to the slab by circulating heated water through a “Slinky” heat exchanger coil installed near the concrete/sand interface. The slinky pipe is made of HDPE plastic and is 500 feet long with a nominal diameter of ¾ in. The pipe was coiled such that the resulting slinky heat exchanger is 40 ft long with a diameter of 3 ft and a 10-in. pitch. The temperature of the concrete surface was measured by two thermistors embedded in the concrete. Slinky supply and return water temperatures were measured by thermistors embedded in the slinky header. Weather data for this study were obtained from the Oklahoma Mesonet weather monitoring network at 15-minute intervals from the Stillwater monitoring station.

Pond Model Validation: Details of this model and the model validation results are described by Chiasson et al. (2000b). Two test ponds were constructed at the Oklahoma State University for this study. The ponds are rectangular with a plan area of 40 ft by 3 ft. Each pond was constructed with vertical sidewalls. One pond is 2 feet deep and the other is 3.5 ft deep. The walls and the bottom of each pond were constructed of reinforced concrete, approximately 8 in. thick. Heat was rejected to each pond by circulating heated water through a Slinky heat exchanger. Each Slinky pipe was of the same construction as described above. The Slinky was positioned horizontally in the 2-ft deep pond vertically in the 3.5-ft deep pond. The temperature of the pond water was measured by thermistors positioned within the pond. Slinky supply and return water temperatures were measured by thermistors embedded in the slinky header. Weather data were acquired as described above.

Development and Validation of a Detailed Water-to-Water Heat Pump Model

Details of this model and the validation results can be found in Jin and Spitler (2000). The overall model approach is to employ deterministic models of each heat pump component part. Each of the fundamental equations describing the system components may have one or more parameters, which are estimated simultaneously using catalog data only; no other experimental data are required. The parameter estimation is done with a multi-variable optimization method. Once the parameters have been estimated, the heat pump model may be used as part of a multi-component system simulation.

This modeling approach has the advantage of not requiring experimental data beyond what is published in the manufacturer's catalog. Yet, its predictions are of similar or better accuracy than previously published deterministic models that required additional experimental data. Unlike the equation-fit models, the model domain may be extended beyond the catalog data without catastrophic failure in the prediction.

Investigation of Control Strategies for Hybrid GSHP Systems

A comparative study to investigate the impact of various operating and control strategies for hybrid GSHP systems that use a cooling tower as a supplemental heat rejecter was conducted through system simulations. Details of this work can be found in Yavuzturk and Spitler (2000). An actual small office building was used in the study and was modeled in two differing climatic regions. Twenty-year life cycle cost analyses were used to evaluate each operating and control strategy in order to determine the lowest cost alternative. The control strategies that were examined can be broadly characterized into three groups: (1) a set point control to operate a cooling tower when the fluid temperature exceeds a set value, (2) a differential control to operate a cooling tower when the difference between the heat pump fluid temperature and the ambient wet bulb temperature exceeds a set value, and (3) a scheduled control to decrease heat buildup in the ground by operating a cooling tower for a given period of time during the night.

A study to investigate the use of the system simulation approach to optimally design a hybrid GSHP system that uses a cooling pond as a supplemental heat rejecter was also conducted. Details of this work can be found in Ramamoorthy et al. (2000). The design challenge lies in finding the optimum size of both the GLHE and the supplemental heat rejecter, which directly depend upon the control strategy used to reject the excess heat. The same building was modeled as in the Yavuzturk and Spitler (2000) study. The design parameters to the component models were varied and the 20-year life-cycle costs of various designs were examined.

RESEARCH RESULTS

The pond and pavement heating model performance were evaluated by comparing (1) the simulated to the observed heat exchange fluid return temperature and (2) the simulated cumulative heat rejected to the measured water heating element and pump power input. The simulated and observed fluid return temperatures are shown in Figure 1 for the 2-feet deep pond and for the concrete slab during the study periods. A review of Figure 1 shows that the model predicts the fluid return temperatures favorably. The average observed and modeled fluid return temperatures over the test period for the 2-feet deep pond were 70.5^{o}F and 70.2^{o}F, respectively and were 73.1^{o}F and 73.4^{o}F for the concrete slab, respectively. At the end of the respective test periods, the percent difference between the cumulative simulated heat rejected and the cumulative measured heat rejected was –2.95 % for the 2-feet deep pond and –5.01 % for the concrete slab. A description of the model, experimental uncertainty analysis, and additional details can be found at: http://www.mae.okstate.edu/Faculty/spitler/pdfs/chiasson_thesis.pdf

The water-to-water heat pump model was validated using catalog data for four heat pumps made by two different manufacturers. Units 1 and 2 were validated using the cooling mode data and units 3 and 4 were validated using the heating mode data. The heat pump capacities, number of operating points given in the manufacturer's catalog, and the root-mean-square (RMS) error for capacity and power are shown in Table 1. The results showed a relatively good agreement with generally acceptable accuracy.

The system simulation investigation of the impact of control strategies on hybrid GSHP system life-cycle cost (Yavuzturk and Spitler, 2000) showed that all of the operating strategies that were examined resulted in significant total cost savings as compared conventional GSHP systems. The analyses suggest that the higher the building cooling loads relative to the heating loads, the more savings can be realized due to reduction in the GLHE size. The most beneficial control strategies were found to be those that operate the supplemental heat rejecter only when the weather conditions are favorable (control strategy 2 described above).

The system simulation approach to determine the optimal size of a hybrid GSHP that uses as cooling pond as a supplemental heat rejecter (Ramamoorthy et al., 2000) used the control strategy 2 (described above). The present values of the cases considered are plotted in Figure 2 versus the ratio of pond loop to total loop length. The cost savings are significant for both climatic regions examined. This study not only demonstrated the benefit of incorporating a supplemental heat rejecter into a GLHE system, but also demonstrated the value of system simulation in supporting the design process of a hybrid GSHP system.

FUTURE PLANS

Funding for this project was terminated as of August 1999 and no future plans exist.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Organization	***Type and Extent of Interest***
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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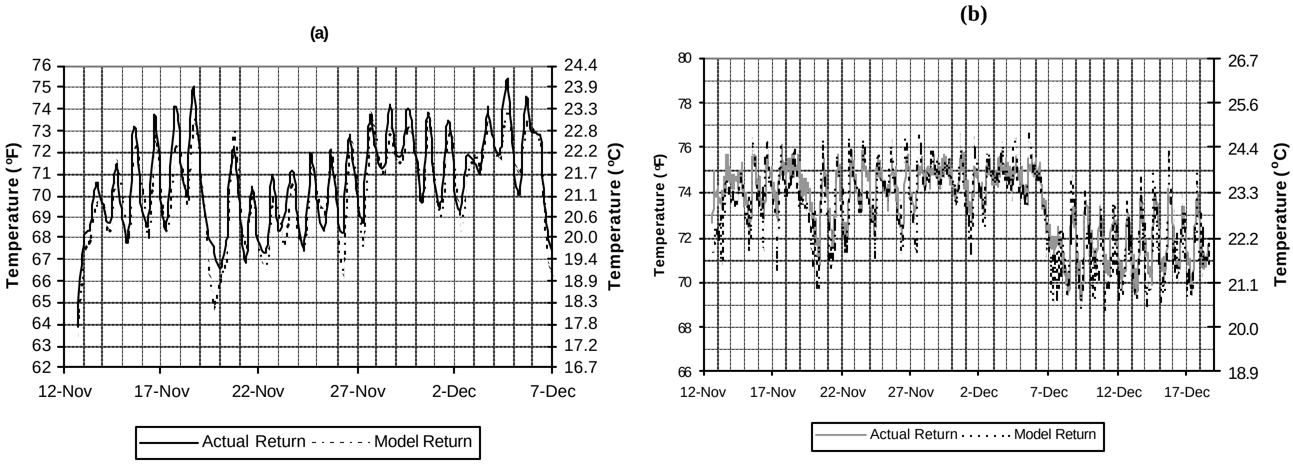

Figure 1. Comparison of observed and simulated heat exchange fluid return temperatures for (**a**) the 2-feet deep pond and (**b**) the concrete slab.

Table 1. RMS Errors of the Water-to-Water Heat PumpSimulations for 4 Sets of Catalog Data

No.	Nominal Capacity		Number of Points	RMS	
	(Btu/hr)	(W)		Capacity	Power
1	9352 – 30951 (cooling)	2741– 9072 (cooling)	81	4.57%	4.77%
2	57472 – 177978 (cooling)	16845 – 52165 (cooling)	81	4.71%	5.44%
3	12122 – 27918 (heating)	3553 – 8183 (heating)	81	2.66%	1.70%
4	174400 – 408500 (heating)	51000-120000 (heating)	234	3.08%	5.76%

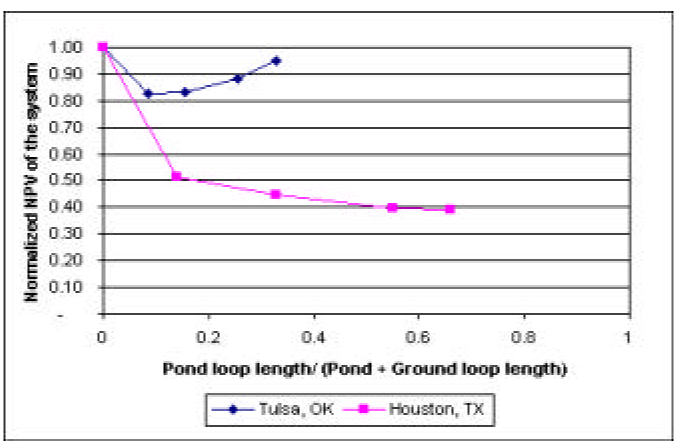

Figure 2. Normalized net present value of the system versus the ratio of pond loop length to total loop length for Houston, TX and Tulsa, OK climatic conditions