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Feasibility of Foundation Heat Exchangers for Residential Ground Source Heat Pump Systems in the United States

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ABSTRACT

Foundation heat exchangers (FHXs) used in residential ground source heat pump systems represent a potential cost savings due to their lesser first cost over other types of heat exchangers. By simulating a foundation heat exchanger system for two low-energy house constructions in seventeen United States locations, a preliminary map detailing the feasibility of FHX systems in the United States has been developed, with most of the country showing at least marginal feasibility for the technology. The FHX simulation process uses decoupled models of house and basement; the coupling between the two zones creates a difference of around 1.0°C (1.8°F) in the simulated maximum or minimum heat pump entering fluid temperature. Additionally, the operation of an FHX in the soil around a house was found to have a negligible impact on soil freezing near the house foundation. The FHX simulation needs a fully coupled house/basement model, as well as the capacity to handle snow cover, to be even more robust.

INTRODUCTION

Ground source heat pump (GSHP) systems are frequently used in residential, commercial, and heating and cooling systems worldwide, with an estimated installed total heating capacity of around 18 GW (61 billion BTU/hr) across 1.7 million units. While GSHP systems are highly efficient, their main disadvantage compared to conventional systems is a significantly higher first cost. This higher cost is due to drilling of either boreholes for vertical ground heat exchangers or excavation for horizontal ground heat exchangers. In general, the length of ground heat exchanger piping and, consequently, the first cost, depend on both the total annual heating and cooling loads and their distribution over the year, as well as ground thermal properties, undisturbed ground temperature, and ground heat exchanger design, as well as other factors.

For homes at or approaching net zero energy, the greatly reduced heating and cooling loads (as compared to conventional construction) provide for the possibility of using a significantly smaller ground heat exchanger. Previous work (Spitler et al. 2010, Xing et al. 2010) has detailed foundation heat exchangers (FHXs) that are placed within the excavation made for the basement and foundation, along with other excavations used for utility trenching. By eliminating separate excavation or drilling, the first cost of the ground heat exchanger may be significantly reduced. Figure 1 shows a schematic of a typical foundation heat exchanger system around a house.

Oak Ridge National Laboratory has demonstrated that an FHX-based GSHP system is feasible for one specific house in one specific climate (Shonder and Spitler, 2009). Additionally, a small-scale study has been performed for several house types in various European climates (Spitler et al., 2010); this study showed that FHX-based systems will function in most climates, but often an additional heat extractor such as a horizontal ground heat exchanger is needed for colder climates. The ground heat exchanger model used for the European study did not include such factors as soil freezing. The present work seeks to identify, via parametric study, how a ground source heat pump system that utilizes a foundation heat exchanger may be applied in various United States locations. By simulating a house using an FHX system in multiple climate zones in the U.S., a better idea of the applicability of this technology in a variety of climate types may be gained. Additionally, this work will explore the influence of the basement, and specifically the coupling between

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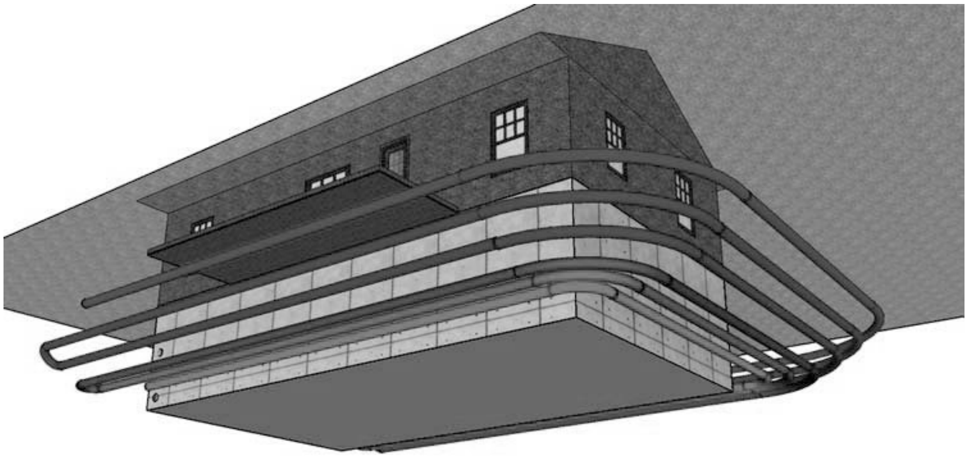

Figure 1 *Schematic of foundation heat exchanger installation around house.*

the basement load and FHX behavior, on the feasibility of these systems.

METHODOLOGY

In order to investigate the range of FHX applicability, a small-scale parametric study was performed. This study involved developing heating and cooling loads for a single-story house for seventeen different locations in United States. This house was constructed to resemble a house used to test the FHX technology, located near Oak Ridge, Tennessee. Two different insulation levels were considered in the analysis. For each combination of location and insulation level, a simulation of the foundation heat exchanger system was run. For cases in which the fluid temperature entering the heat pump exceeded design limits, an auxiliary horizontal ground heat exchanger was added to the system and another simulation performed. One concern during these simulations is the possibility of thermal "short-circuiting": increasing the load on the system by altering the ground temperature outside the basement. This effect is analyzed and accounted for during the simulations. Each aspect of this methodology is described in detail below.

Heating and Cooling Loads for Prototypical Houses

House Description. To test the behavior of the FHX system in various locations, a prototype house based on the experimental house near Oak Ridge, Tennessee (Shonder and Spitler 2009), was created in the EnergyPlus environment (Crawley 2001). The house has a floor area of 148 m^2 (1590 ft^2) and an aspect ratio of 1.56, with a structural insulated panel construction. Glazing occupies 29% of the north and south façades and 3% of the east and west façades; the windows have a U-value of 1.8 W/m^2–K (10.2 Btu/hr–ft^2–°F) and a solar heat gain coefficient (SHGC) of 0.36. The house has a combined 8.2 W/m^2 (25.9 Btu/hr–ft^2) of lighting and casual gains, with a total of 300 m^2 (3230 ft^2) of simple internal thermal mass and a constant infiltration rate of 0.5 ach. The house is maintained at setpoints of 24.5°C (76°F) in cooling and 21.7°C (71°F) in heating. For the purposes of this study, the basement is assumed to be conditioned only by heat exchange with the conditioned portion of the house.

Two versions of the house were created, one based on current best practice in design, and one exceeding best practice. The best practice design (hereafter referred to as "HI" for "high insulation") has all the above characteristics, including walls made of R-28 structural insulated panels. The enhanced design (called "VHI" for "very high insulation") uses R-42 structural insulated panels and also includes an air-to-air heat recovery unit on a dedicated outdoor coil.

Climate Zones. A set of seventeen locations, representing a variety of climates and latitudes in the United States, was chosen for this study. To classify the climate types, a recent update of the Köppen-Geiger climate classification scheme (Kottek et al. 2006) was consulted. At least one location was selected in each of the main U.S. climate zones. A complete listing of the locations used in the study, along with their Köppen-Geiger classification zones, is given in Table 1. The TMY weather files for each of these locations were used as input data to both the EnergyPlus load generation and HVACSIM+ foundation heat exchanger system simulations.

Simulation of Foundation Heat Exchangers and Heat Pump System

The foundation heat exchanger is modeled using a two-dimensional, explicit finite volume algorithm, implemented in the HVACSIM+ simulation environment (Clark 1985). The domain extends 4 m (13.1 ft) to the right of the basement wall, 5 m (16.4 ft) below the ground surface, and to the left below the basement to the centerline of the house. A non-uniform grid consisting of approximately 13,000 cells is utilized, with cell spacing fine around the FHX pipes as well as heat transfer surfaces, and increasing toward the edges of the domain. The initial conditions and lower boundary condition are set with the Kusuda and Achenbach (1965) model, using parameters computed from a one-dimensional ground heat transfer model

Table 1. Parametric Study Locations

Location	Köppen-Geiger Climate Classification
Baltimore, MD	Cfa (temperate, humid, hot summer)
Billings, MT	BSk (arid steppe, cold)
Charleston, WV	Cfb (temperate, humid, warm summer)
Chicago, IL	Dfa (snowy, humid, hot summer)
Cleveland, OH	Dfa (snowy, humid, hot summer)
Denver, CO	BSk (arid steppe, cold)
Houston, TX	Cfa (temperate, humid, hot summer)
Knoxville, TN	Cfa (temperate, humid, hot summer)
Las Vegas, NV	BWh (arid desert, hot)
Minneapolis, MN	Dfb (snowy, humid, warm summer)
Phoenix, AZ	BWh (arid desert, hot)
Salem, OR	Csb (temperate, dry and warm summer)
Salt Lake City, UT	BSk (arid steppe, cold)
San Francisco, CA	Csb (temperate, dry and warm summer)
St. Louis, MO	Cfa (temperature, humid, hot summer)
Tallahassee, FL	Cfa (temperature, humid, hot summer)
Tulsa, OK	Cfa (temperate, humid, hot summer)

with typical weather conditions for the location. The vertical boundaries are assumed to be adiabatic; below the house, this is due to symmetry, while the size of the domain was specified so that the far-field boundary would have negligible influence.

The ground surface heat balance, shown in Figure 2, includes the typical heat transfer phenomena of surface conduction, convection due to wind, and both short- and long-wave radiation, in addition to evapotranspiration. Conduction is computed based on the governing Laplace equation, while convection is computed based on the McAdams correlation (1954). The radiation terms are computed along with evapotranspiration, as they are needed for its calculation. The evapotranspiration, which describes the heat loss due to moisture transfer through surface vegetation, is determined using the formulation of Walter et al. (2005) assuming a standard grass of uniform 120 mm (4.7 in.) height with a moderately dry soil surface. Other methods of moisture transfer are not included in the model. Snow cover on the ground surface is also neglected. Recent work (Xu and Spitler 2011) has indicated that the additional accuracy gained from considering water migration is negligible, especially considering the additional computation time required to analyze it; the issue of how best to handle snow cover is still under investigation. However, freezing and thawing of the moisture in the soil is included, as shown in Figure 2, using an effective heat capacity method (Lamberg et al. 2004). This method artificially adjusts the volumetric heat capacity of the soil as a function of temperature so that the net energy gain or loss is the same as in the actual freezing process. This is done over a range of 0.5°C (0.9°F) near the freezing point, instead of entirely at 0°C (32°F), though. Specific values are computed based on the soil water content, using the equations suggested by Niu and Yang (2006).

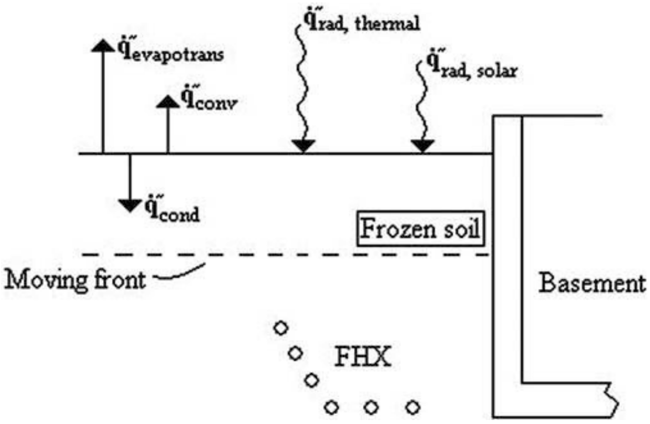

Figure 2 *Foundation heat exchanger surface heat balance including soil freezing front.*

The FHX system model also includes a simple heat pump model. The heat pump is represented as second-order equation fits relating the heating and cooling COPs to the heat extracted or rejected, with coefficients determined from experimental data. Since the heat pump entering fluid temperature is needed to determine the COPs, some iteration is needed to determine the exact performance; this is handled by the HVACSIM+ environment.

The model has been validated (Xing et al. 2011) against twelve months of experimental data collected at a test house by Oak Ridge National Laboratory near Knoxville, Tennessee. The one-dimensional ground temperature response has been validated against sub-surface measurements made at multiple weather stations in the United States (Xing 2010). The grid size and the extent of the soil domain have both been chosen to give both grid independence and domain size independence. The model has several limitations based on un-modeled phenomena such as moisture transport in the soil and snow accumulation; these things are ignored in the current FHX model.

A very similar model for horizontal ground heat exchangers that may be placed in utility trenches has also been developed. This model is essentially identical, except that there is no basement wall present. For this study, the HGHX consists of six pipes oriented similarly to the foundation heat exchanger, as this is the configuration that was installed in the experimental facility.

A more thorough discussion of the foundation heat exchanger model may be found in Xing (2010).

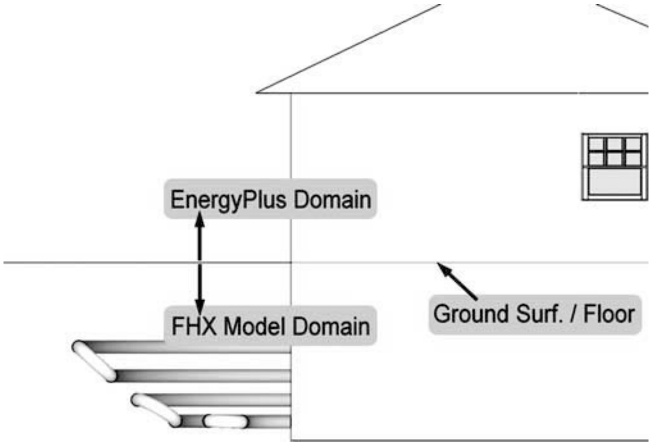

Figure 3 *Calculation domains describing responsibilities of EnergyPlus and FHX models.*

Coupling of Computational Domains

There are two separate computation domains used in simulating the behavior of the foundation heat exchanger system, above-grade and below-grade, and a separate simulation program for each domain. Figure 3 shows the two domains. EnergyPlus is used to model the house, while the FHX model (in HVACSIM+) accounts for the behavior of the soil and basement. These two calculation regions are coupled in that the whole building loads have a direct effect on the ground thermal response, and the ground thermal response will have an effect on the load in the basement. However, the simulations themselves are decoupled and do not interact with one another.

For a given combination of building and location, EnergyPlus is used to calculate the hourly above-grade building heating and cooling loads. These loads then need to be augmented with the basement heating (or cooling) loads to arrive at a total house load. The foundation heat exchanger model is then used to simulate everything below-grade, including the basement zone, wall, and floor, as well as the ground to the far-field boundary, which contains the foundation heat exchanger pipes. The foundation heat exchanger model, described above, calculates the amount of heat transferred through the basement wall and floor. This heat transfer is then reported hourly as the "basement load."

With a basement load and an above-grade load, the total load for the house is directly calculable using the process shown in the flowchart in Figure 4. Since the simulation programs handling the two computational domains are decoupled, this process is not direct. First, EnergyPlus must be run to report the above-grade house loads. This is fed into the foundation heat exchanger model as input to the heat pump simulation to generate a temperature response. This temperature response will result in a certain basement load, which must then be added back to the original above-grade house load to determine an updated total house load. This load is fed into the foundation heat exchanger model, and a slightly different temperature response will occur. This temperature response will then cause a different basement load and therefore a different overall house load. This process continues until the house load converges between one step and the next.

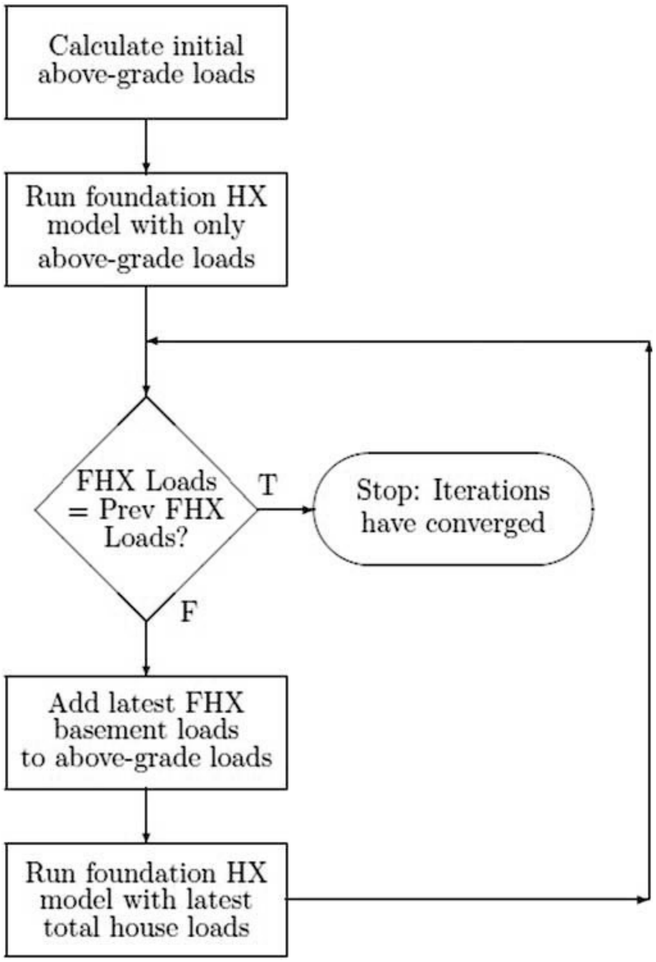

Figure 4 *Iterative approach to combining loads between standalone EnergyPlus and FHX models.*

One key note about this procedure is that the above-grade portion of the load need only be calculated once per location. The basement load is calculated directly as the heat transfer conducted through the walls and floor. The above-grade loads are calculated as effectively the air-side coil load on a heat pump. By adding these two directly together, two assumptions are being imposed:

- The basement is incidentally conditioned by heat transfer through the floor and via interzone airflow but has no effect on the above-grade loads calculated previously.
- The heat transfer from the basement walls is immediately conditioned and absorbed by the air conditioning system. In an annual simulation, these effects will be

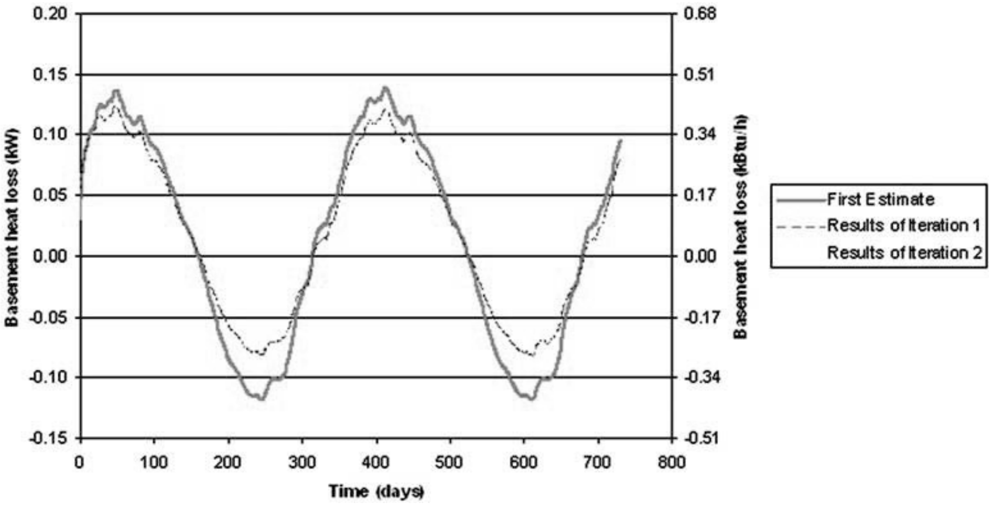

Figure 5 *Effect of load coupling between basement and living space for Houston (high-insulation case).*

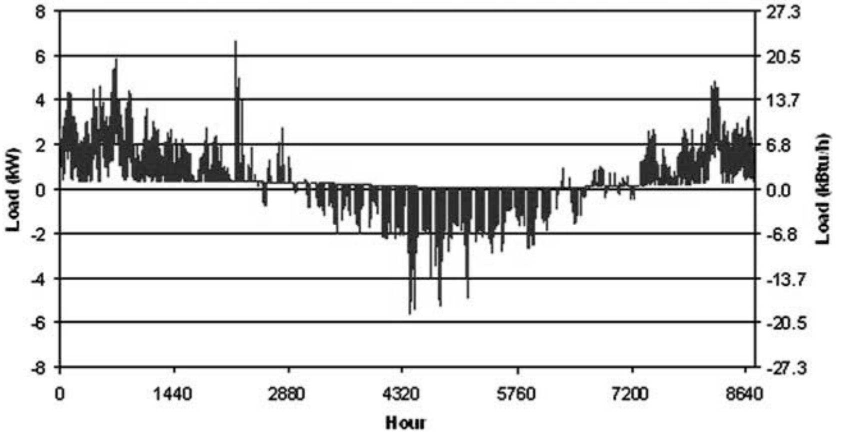

Figure 6 *Load profiles for high-insulation house in Minneapolis.*

minimal because the heat would eventually be absorbed anyway; there may be a lag in reality, however.

The result of this iteration process is a matched total house load and ground thermal response. For each case, the additional heating required was initially estimated from the case with no foundation heat exchanger in the same location. This was done by determining the heat that exited the basement through the wall and slab. Figure 5 shows the heating requirement as initially estimated, and as determined after each of the first two iterations, for the high-insulation case in Houston. From the figure, it is clear that the initial estimate has some inaccuracy; the additional heating requirement due to the basement is altered slightly by the presence of the foundation heat exchanger. However, the first and second iterations are so close that the curves overlay each other. The resulting difference in heat pump entering fluid temperature due to this difference in building load is about 0.5–1.0°C (0.9–1.8°F), which could be enough to alter a decision on whether the FHX-only system is feasible and whether a supplemental heat exchanger may be necessary. Regardless of the location, the basement heating requirement converged to within 10 kWh (34 kBtu) over the year after two iterations.

RESULTS

For each location, a simulation was run with the foundation heat exchanger completely surrounding the house for both the high- and very high-insulation cases. Each simulation was run for two years in order to mitigate any effect due to uncertainty in the initial soil temperature profile. Load profiles, with heating shown as positive and cooling negative, are given in Figures 6 and 7 for the high-insulation houses in Houston and Minneapolis, respectively. Since the houses are designed to be extremely low-energy, the heating and cooling load profiles are a bit different from those of conventionally constructed houses. Because the houses are designed to have extremely

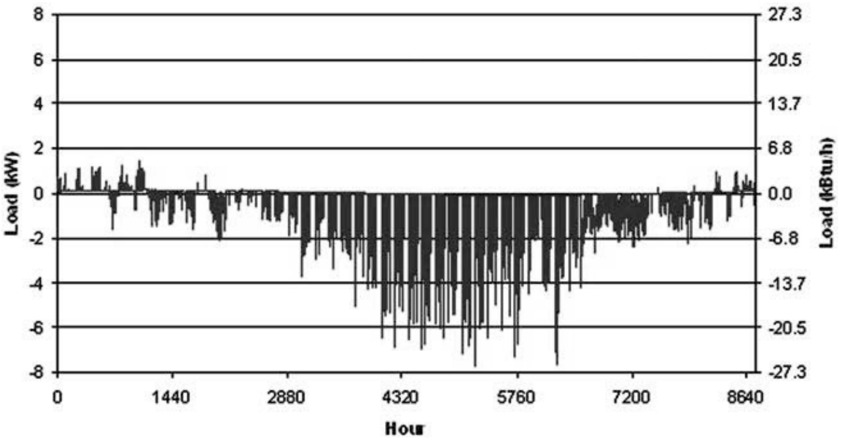

Figure 7 *Load profiles for high insulation house in Houston.*

Table 2. Heat Pump Minimum and Maximum EFTs

Location	Minimum EFT, °C (°F)		Maximum EFT, °C (°F)	
	VHI	HI	VHI	HI
Baltimore, MD	4.37 (39.87)	3.06 (37.51)	28.51 (83.32)	28.90 (84.02)
Billings, MT	–0.86 (30.45)	**–2.13 (28.17)**	19.53 (67.15)	**19.37 (66.87)**
Charleston, WV	3.72 (38.70)	2.21 (35.98)	28.15 (82.67)	28.68 (83.62)
Chicago, IL	–0.54 (31.03)	**–1.52 (29.26)**	24.11 (75.40)	**25.22 (77.40)**
Cleveland, OH	–0.12 (31.78)	–0.91 (30.36)	24.04 (75.27)	24.00 (75.20)
Denver, CO	2.81 (37.06)	1.33 (34.39)	21.76 (71.17)	21.61 (70.90)
Houston, TX	15.04 (59.07)	**14.52 (58.14)**	37.31 (99.16)	**38.12 (100.62)**
Knoxville, TN	8.02 (46.44)	6.82 (44.28)	32.07 (89.73)	32.52 (90.54)
Las Vegas, NV	11.33 (52.39)	10.73 (51.31)	31.81 (89.26)	32.95 (91.31)
Minneapolis, MN	**–2.74 (27.07)**	**–3.97 (24.85)**	**21.68 (71.02)**	**22.67 (72.81)**
Phoenix, AZ	**16.31 (61.36)**	**15.75 (60.35)**	**39.12 (102.42)**	**40.49 (104.88)**
Salem, OR	6.69 (44.04)	5.84 (42.51)	21.23 (70.21)	20.84 (69.51)
Salt Lake City, UT	3.71 (38.65)	2.35 (36.23)	23.26 (73.87)	23.58 (74.44)
San Francisco, CA	12.19 (53.94)	11.90 (53.42)	20.66 (69.19)	20.09 (68.16)
St. Louis, MO	3.22 (37.80)	1.76 (35.17)	30.44 (86.79)	31.46 (88.63)
Tallahassee, FL	16.53 (61.75)	**15.93 (60.67)**	36.76 (98.17)	**37.86 (100.15)**
Tulsa, OK	5.98 (42.76)	4.77 (40.59)	32.63 (90.73)	33.66 (92.59)

low infiltration, cooling loads will be somewhat higher in the summer as the solar radiation entering the house cannot be mitigated by incoming airflow. In the winter, for much the same reason, the heating requirements will be slightly depressed. Overall, the total load will still be quite a bit smaller than for a conventional house, which allows the foundation heat exchanger system to work for some locations without any additional heat extraction or rejection components.

Table 2 shows the minimum and maximum heat pump entering fluid temperatures over the two-year simulation period for each combination of location and insulation level; in bold are those cases that fail to meet the design constraints

Table 3. Heat Pump EFTs for FHX+HGHX System

Location	Minimum EFT, °C (°F)		Maximum EFT, °C (°F)	
	VHI	HI	VHI	HI
Billings, MT	---	0.01 (32.02)	---	---
Chicago, IL	---	0.60 (33.08)	---	---
Houston, TX	---	---	---	31.70 (89.06)
Minneapolis, MN	–0.45 (31.19)	–1.09 (30.04)	---	---
Phoenix, AZ	---	---	32.10 (89.78)	32.75 (90.95)
Tallahassee, FL	---	---	---	31.43 (88.57)

on the heat pump EFT of –1.0°C (30.2°F) in heating and 37.5°C (99.5°F) in cooling, with a working fluid of 10% propylene glycol. In total, there are four cases (Billings HI, Chicago HI, and Minneapolis HI/VHI) that fail to meet the minimum constraint and four (Houston HI, Phoenix HI/VHI, and Tallahassee HI) that fail to meet the maximum constraint. These represent the coldest and warmest climates tested, respectively; thus, a foundation heat exchanger by itself would be infeasible for these locations. For each of these eight cases, a 100 ft (30.5 m) horizontal ground heat exchanger will be added to the system and the feasibility tested once more. Additionally, the locations that are closest to the constraints without breaking them are in the more extreme climates—Cleveland and Denver, for example, are in the Dfa classification, while Las Vegas is in the BWh zone and both Tulsa and Knoxville are in the Cfa zone.

For the eight cases that exceeded one of the design limits, a 100 ft (30.5 m) horizontal ground heat exchanger was added to the system, in series with the FHX. Table 3 shows the resulting minimum and maximum heat pump EFTs for these systems. After adding the HGHX, only the Minneapolis case with the high insulation level still violates the temperature constraint. When adding the HGHX, the maximum temperatures decrease by around 5–8°C (9.0–14.4°F), while the minimum temperatures increase by only around 2–3°C (3.6–5.4°F). This is because of the sizable amount of energy required to thaw the soil; instead of decreasing the temperature further, the additional energy is used to freeze the moisture in the ground.

Figure 8 shows the recommended feasibility of foundation heat exchangers for use in ground source heat pump systems in the United States. There are three zones of feasibility: not recommended, marginal, and feasible. The lines separating these areas were drawn to separate the locations based on the simulation results presented in Tables 2 and 3, with the lines following borders between Köppen-Geiger climate zones as closely as possible between the seventeen studied locations. Since the high-insulation house represents current recommended best practice, those results were used for the map in Figure 8. The "not recommended" zone indicates locations (such as Minneapolis) where a foundation heat exchanger cannot be expected to work, even with the addition of a supplemental horizontal ground heat exchanger. The "marginal" zone includes both locations that might require a supplemental HGHX (such as Billings and Houston) and locations where the heat pump EFTs may be fairly close to the constraints—say, two degrees or so. Finally, the "feasible" area contains the locations where a foundation heat exchanger may be expected to work without supplement from another heat exchanger. However, it should be remembered that the FHX systems were only tested with very well-insulated, low-energy houses, so the feasibility of an FHX for a more typical construction cannot be guaranteed even in the "feasible" zone of Figure 8. Additionally, climates on a local scale, particularly in the western United States, are not reflected in the map. However, the figure should give a preliminary indication of how well foundation heat exchangers may be suited for residential applications in general.

One other factor to consider when placing a foundation heat exchanger around a building is the impact that the FHX will have on the total building loads. Figure 9 shows the additional heating required because of the interaction between ground and basement, both in the presence of the FHX and without an FHX system, when the house is conditioned as described previously and the basement temperature is tied to the house by a thermal resistance term. Overall, the values are roughly equivalent at each location. However, in colder locations such as Billings and Minneapolis, the values are slightly higher when there is an FHX present, due to an increase of heat transfer out of the basement due to cold pipes on the outside of the basement wall. Similarly, the additional heating load due to the basement is slightly lower for the hotter locations such as Houston, Phoenix, and Tallahassee, since the pipes outside the basement wall are generally warmer than the surrounding earth, which results in more heat entering the basement. Additionally, these basement loads contribute about 25% of the building heating load, although the exact figure depends on the insulation level of the house. The additional basement cooling load due to the presence of the FHX is also slightly altered, but

Figure 8 *Preliminary feasibility of foundation heat exchangers for residential ground source heat pump systems.*

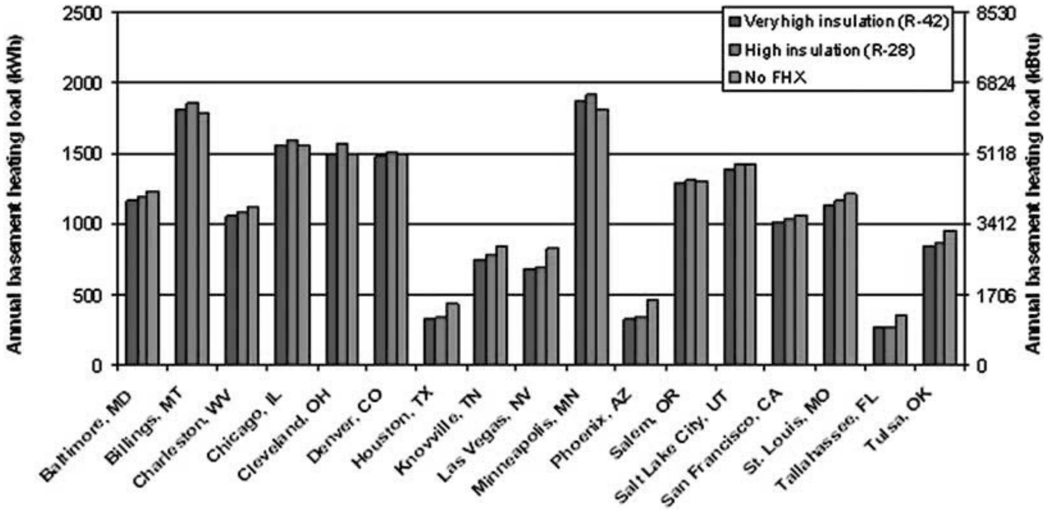

Figure 9 *Additional heating requirement due to basement-ground interaction for the second year.*

this effect is much lower than the heating effect due to the high-efficiency house construction.

One major concern with the installation of any heat exchanger near the foundation of a building is that the process of extracting heat from the ground around the building will cause the soil next to the foundation to freeze. Obviously, long-term freezing or frequent freeze/thaw cycling may create structural problems in the foundation. To explore the possibility of soil freezing for foundation heat exchanger systems, the soil temperature at the foundation wall was checked for the coldest location, Minneapolis. Figure 10 shows the soil temperatures 25 mm (1 in.) from the foundation wall at four different depths for the high-insulation case in Minneapolis. For roughly 100 days during each of the two winters, the temperature remains below freezing at the foundation wall. This could very easily cause issues with the building foundation. It would be of interest to know, then, to what extent that the FHX contributes to this soil freezing. Figure 11 shows the temperatures in the soil domain for January 31 of the second year of simulation; January 31 was identified as the coldest day from Figure 9, while the second year's results were used to mitigate any possible confusion of

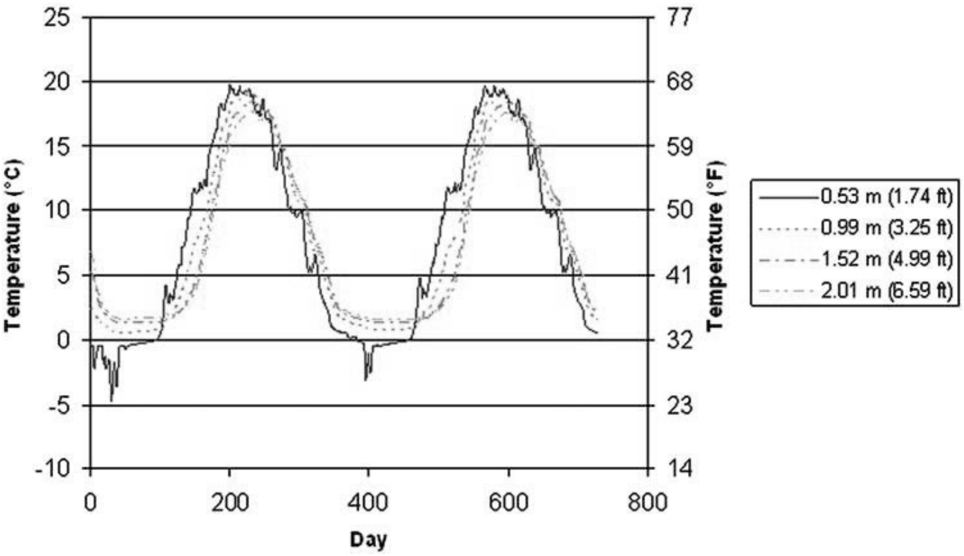

***Figure 10** Daily variation of temperatures along house foundation for Minneapolis (high-insulation case).*

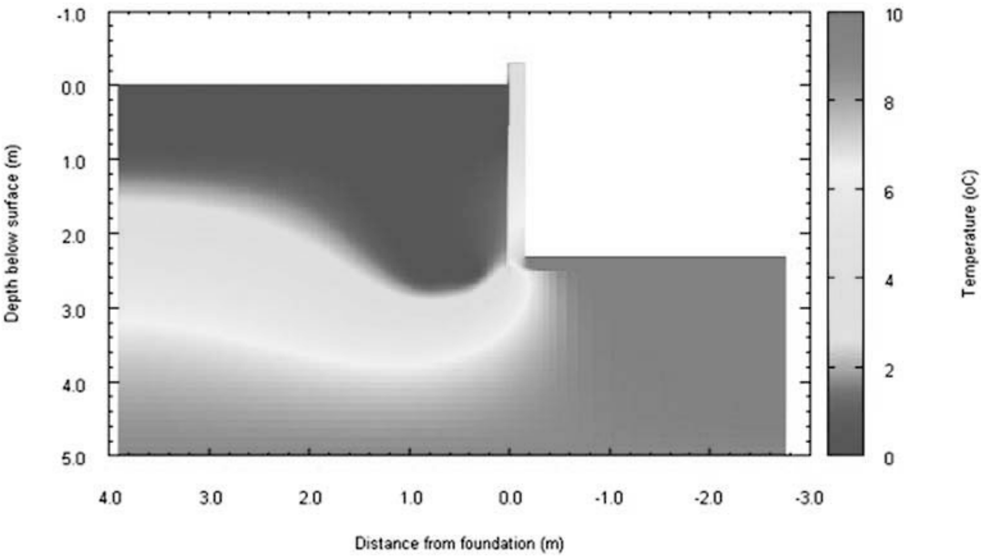

***Figure 11** Soil temperatures on January 31 of second year for Minneapolis high-insulation case.*

effects from the temperature initialization. There are two noticeable areas of freezing: around the FHX piping and a uniform depth at the surface. While the soil does indeed freeze around the FHX piping, the freezing front never reaches the house foundation; the sub-freezing temperatures along the foundation are entirely due to weather effects, as the soil is frozen to a depth of about 0.9 m (3.0 ft) along the entire length of the soil domain. Thus, it can be concluded that the addition of an FHX will most likely not require any additional consideration of protecting the foundation from freezing, aside from what would be normal for any typical building in that particular location.

CONCLUSIONS

This work has detailed an investigation into the possible usage of foundation heat exchangers in ground source heat pump systems in the United States. FHXs were used for houses in seventeen locations in a range of climate types, assuming that the FHX encircles the entire perimeter of the house. Of the cases examined, eight (four in heating and four in cooling) resulted in FHXs that exceeded the heat pump entering fluid temperature design limits; adding a 100 ft (30.5 m) horizontal ground heat exchanger to the system brings the heat pump EFTs to within the design limits in all but one case—the high-insulation-level house in Minneapolis. From these results, a preliminary map of the feasibility of foundation heat exchangers for usage in ground source heat pump systems in the United States was generated; three different areas of feasibility were identified. While this map was drawn considering only a single house type and FHX configuration, it should give an indication of how well the technology might be expected to perform in general. It should be noted that the feasibility described here only refers to the handling of physical phenomena; economic factors will also affect the feasibility of actually implementing an FHX system.

Also, the possibility of soil freezing along the foundation was investigated, and it was found that the presence of the FHX did not add to the freezing of the soil near the foundation, even for the coldest location tested. Instead, the only significant cause of soil freezing at the foundation is weather effects. Further exploration of the influence of snow accumulation and melting, and the associated moisture migration, will improve understanding of all of the phenomena that influence the behavior of the FHX.

Additionally, the issue of the coupling between above-grade and below-grade calculation domains was examined. An initial estimate of the interaction between house and basement, found by simulating under the assumption that the heat exchanger is off, provides what seems like a good representation of the additional load due to the basement. However, the difference between the initial estimate and the final value, determined via iteration, results in a difference in heat pump EFTs as large as 1°C (1.8°F). Thus, even though the domains are decoupled, the interaction between them is still quite significant. A more thorough investigation will require a complete, integrated model of house, basement, and heat exchanger; this is a topic currently under development.

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