Photo 1 (left): Installation of the insulated concrete form (ICF) foundation blocks around Equinox House perimeter. Note the plastic web that both holds the Styrofoam walls together and supports the rebar. **Photo 2 (right):** ICF foundation wall prior to pouring concrete. Note that the concrete footer below the ICF wall is close to the original grade of the surrounding ground.

Ground Heat Transfer

By **Ty Newell,** Member ASHRAE; and **Ben Newell,** Associate Member ASHRAE

With few exceptions, visitors to Equinox House ask how much insulation is below the concrete slab floor. There is no insulation below the floor. Ground heat transfer in buildings is an important factor, especially in regard to superefficient buildings. But it's difficult to analyze, model, and predict. In designing Equinox House, we looked at the foundation wall and underslab ground heat transfer in relation to the house loads and energy cost to decide whether to use insulation.

The coupling between a building and the ground is difficult to define due to the transient, multidimensional analyses required along with a general lack of property information for soils in a specific location. For our design assessment, we constructed a finite volume heat transfer model. The simulation is a three-dimensional, transient model that solves an implicit form of the conduction equation for the ground and foundation wall regions. We define a region that extends 30 m (100 ft) horizontally from the building perimeter and 5 m (16 ft) below the floor to a level where we define a constant ground temperature of 10°C (50°F). Computational cells are 1 m by 1 m (39 in. by 39 in.) in horizontal dimensions by 99 mm in depth (3.9 in.). Approximately three years of iterations are required to reach a cyclical thermal steady state.

Soil properties are always a problem. What type of soil? How wet is the soil? The structure's floor is quite complicated as well. Underneath the slab are thickened concrete regions under the internal bearing walls, some internal piers that tie into the footer but leave the insulated concrete form (ICF) wall intact, some sand in the plumbing drain trenches, fill from who knows where, and crushed rock. Under the house, the soil most likely dries out, while the exterior ground varies throughout the year with changes in moisture and freezing. We did not incorporate freezing or varying properties into the model. We explored a range of soil thermal diffusivities (~3 to 8 × 10^{-7} m^2/s [32.3 to 86.1 ×10^{-7} ft^2/s]), representing dry, low thermal conductivity to wet, higher thermal conductivity soils. Floor surface effects such as carpets or other flooring, along with structures (tables) that radiatively block the floor's view of other room surfaces have been examined, and we have found that their impact is not significant with the ground's internal resistance dominating the situation.

This is the sixth in a series of columns. Find previous columns at www.ashrae.org/ashraejournal.

We present results with the lower soil diffusivity value for this discussion, which is based on the assumption that our slab is significantly above groundwater level and that the warmer slab will move moisture out of the underlying ground. A detailed soil energy transport investigation by Deru and Kirkpatrick[1,2] indicates that this property range produces average slab heat fluxes in the 2 to 5 W/m^2 range (0.64 to 1.59 Btu/h·ft^2).

The foundation wall surrounding Equinox House is constructed with insulated concrete forms for an R22 perimeter insulation value. The ICF is made of two 3 in. (76 mm) thick layers of Styrofoam held together with plastic cross pieces. The plastic cross pieces hold rebar in place for the concrete poured between the Styrofoam walls. *Photos 1* and *2* (Page 62) show the installation of the ICF foundation block, while *Photo 3* shows an exterior view of the ICF after concrete was poured. *Photo 4* shows the poured concrete floor slab. The slab floor and finished exterior grading are level, resulting in barrier free entrances. *Figure 1* shows the ICF foundation wall, footer, and concrete slab floor. Frost depth in our region, on average, is 0.51 m (20 in.), with local building codes requiring a footer depth that is below 0.81 m (32 in.). The footer is uninsulated and is treated as having the same properties as the surrounding ground because the thermal diffusivity of concrete is similar enough to ground (approximately 7×10^{-7} m^2/s [75×10^{-7} ft^2/s]). We assumed a depth of 1 m (39 in.) for the depth of the foundation wall below grade, similar to the 1.02 m (40 in.) depth of the foundation wall below grade.

Photo 3: Concrete poured in ICF foundation wall. The exterior ground is graded to 8 in. (200 mm) below the top of the ICF foundation wall.

Photo 4: Floor slab and exterior grade are 8 in. (200 mm) below the top of the ICF foundation wall to provide barrier free entrances into Equinox.

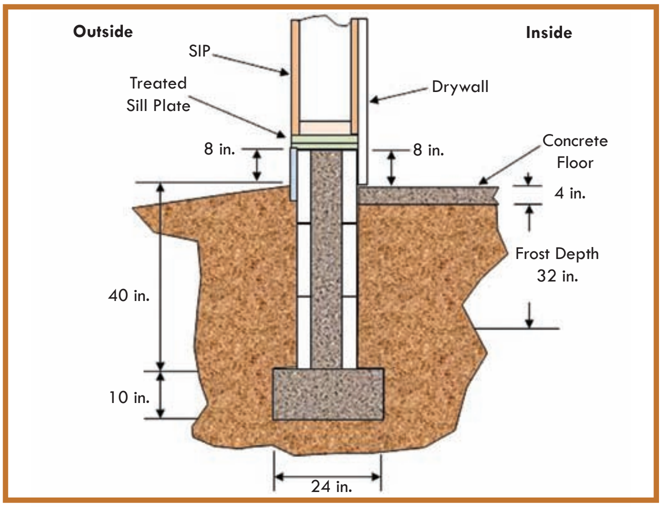

Figure 1: ICF foundation wall details for Equinox House.

Most would agree that having a well insulated foundation wall that extends below the frost line is a must in a climate zone such as Illinois. Our ground model results support this. *Table 1* shows ground model results for a variety of situations. Case 3 is an ICF

Case	House Description	Ground Energy (kWh)	Electric (kWh)	Solar Cost ($)	Solar Array (ft^2)	Floor Insulation Cost ($)
1	Constant Ambient Temperature ICF, No Slab Insulation	4,200	7,310	23,925	468	0
2	Constant Ambient Temperature Perfect Ground Insulation	0	6,470	21,175	414	–
3	Variable Ambient Temperature ICF, No Slab Insulation	4,050	6,720	22,000	430	0
4	Variable Ambient Temperature Perfect Ground Insulation	0	5,840	19,250	376	–
5	Variable Ambient Temperature 6 in. EPS	2,140	6,660	21,725	425	5,000
6	Variable Ambient Temperature 12 in. EPS	1,490	6,590	21,450	420	10,000
7	Variable Ambient Temperature No ICF or Underslab	4,930	7,090	23,100	452	0

Table 1: Comparison of Equinox House annual energy predictions, solar array cost, and solar array size due to foundation heat loss. Constant ambient temperature assumes interior ambient temperature is 22°C (71.6°F) all year. Variable ambient temperature assumes monthly varying interior ambient temperatures with NDJFMA=21°C; M=22°C; J=24°C; J, A=25°C; S=24°C; O=22°C.

foundation wall, and Case 7 is an uninsulated foundation wall. The results show that the extra foundation insulation cost of $1,875 is justified to reduce the yearly house electrical energy 370 kWh from 7,090 to 6,720 kWh. We have assumed the insulation to cost $175/m^3 (\$5/ft^3). If instead a larger solar PV system were installed to make up for this energy, it would cost $1,100. Over 100 years it would cost roughly $5,000 assuming five solar system replacements.

The more contentious design decision was whether to insulate under the concrete floor. We chose to pour the floor without insulating below the slab based on our simulation results. Our laboratory also has an uninsulated slab floor. The floor in our lab does not have perimeter insulation, and yet, throughout the year, the floor and ceiling are within 1°C (2°F) of each other throughout the year as our simulation model predicts. Approximately 3 to 6 ft (0.9 to 1.8 m) of the floor perimeter will be 2.8°C to 5.6°C (5°F to 10°F) lower than the central floor region during the bitter cold of winter due to the lack of exterior perimeter insulation.

A prevalent notion among many is that uninsulated concrete floors are cold. We often ask people to guess the temperature difference between the ceiling and the floor, and most guess more than 6°C (10°F). While concrete may have a cold "feel" as do other masonry floors due to its thermal diffusivity, it is not cold. Arbitrarily insulating below the floor can adversely impact construction cost and performance cost. *Photo 5* shows a comparison of the floor and ceiling temperature in Equinox House on a hot day. There are no ceiling fans (a cost savings) in Equinox House even though the ceiling height is 6.1 m (20 ft). Radiative transfer minimizes stratification in superinsulated enclosures. *Figures 2*

Photo 5: Equinox ceiling temperature and the temperature of the uninsulated concrete floor are shown on the handheld infrared thermometer display. It was a 91°F (33°C) day on Sept. 23, 2010 in Urbana, Ill.

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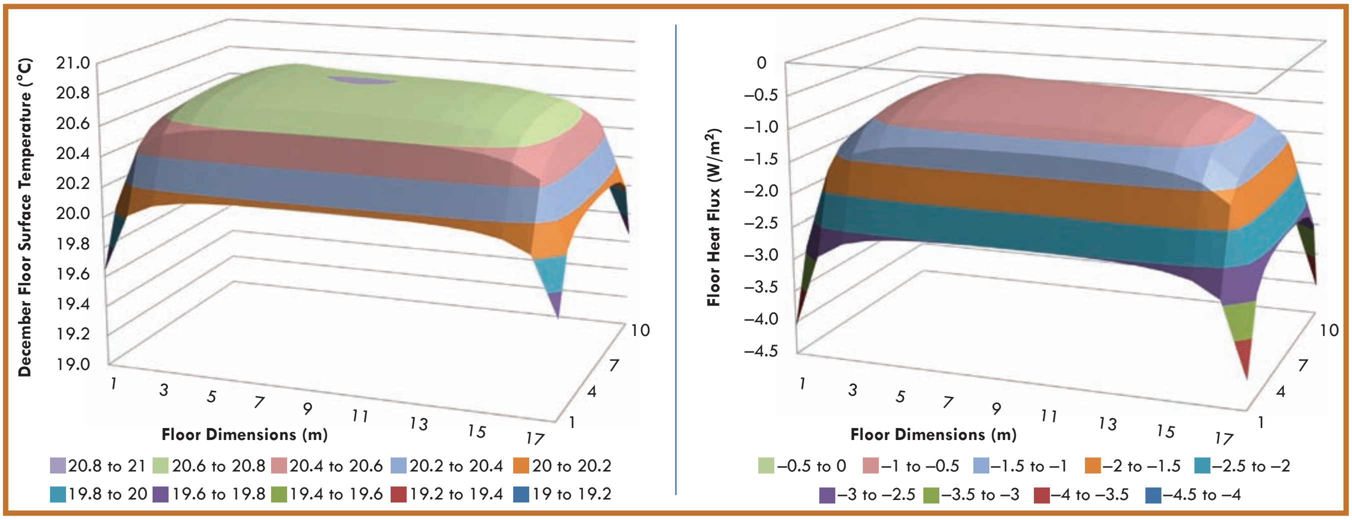

Figure 2 (left): Floor surface temperatures during December 2010 with interior ambient temperature of 21°C (69.8°F). **Figure 3 (right):** December floor surface heat flux levels with an interior ambient temperature of 21°C (69.8°F) and a ground temperature of 10°C (50°F) at depths below 5 m (16.4 ft).

and *3* show the floor surface temperature and heat flux from the simulation model for Equinox House in December. At the depth of the footer (1 m [39 in.]) in December, the average ground temperature around the perimeter of the house is 8°C (46.4°F).

We also conducted the simulations because we were interested in transient effects of foundations on Equinox House energy performance. Can the ground below a slab be a beneficial seasonal storage mass? Or, will it be a detriment that should be isolated with insulation? Some superinsulated home builders are placing as much as 300 to 400 mm (12 to 16 in.) of Styrofoam below their floors. With a material cost of $\$175/\text{m}^3$ ($\$5/\text{ft}^3$), this would be a cost of $10,000 to $15,000.

Results from seven foundation situations, Cases 1 through 7, are shown in *Table 1*. As previously mentioned, Case 3 is the Equinox House configuration with ICF foundation walls and no slab insulation. For Cases 1 and 2, the building interior ambient air temperature is held constant throughout the year at 22°C (71.6°F). The varying ambient temperature cases in *Table 1* means November through April are assumed to have an interior ambient temperature of 21°C (69.8°F), May and October are 22°C (71.6°F), June and September are 24°C (75.2°F), and July and August are 25°C (77°F), for an average annual interior ambient temperature of 22.3°C (72.1°F).

Figure 4 compares the ground heat transfer for the ICF foundation with uninsulated slab floor cases with constant interior ambient temperature and with variable interior ambient temperature. It's intuitive that setting the thermostat closer to the outside ambient temperature will reduce building conditioning loads. What is not so apparent is the interaction and impact with the ground heat transfer. Over the course of the year, the total energy transferred to the ground is the same, however the annual distribution of energy transfer significantly impacts the overall house energy requirements. The uninsulated floor with constant interior ambient temperature (Case 1) has less than 10% variation in monthly heat transfer, with an average heat flux of

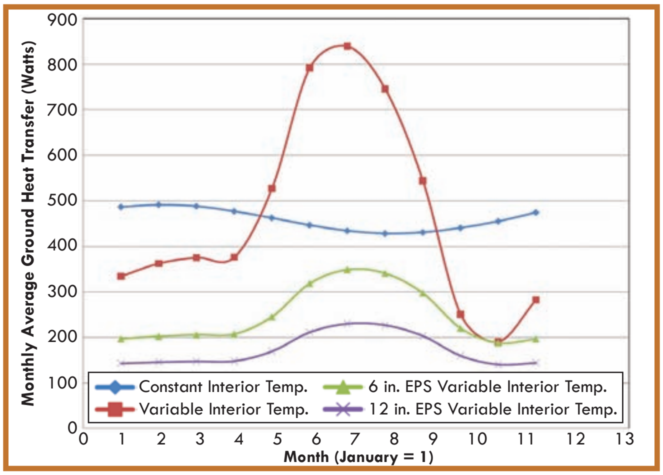

Figure 4: Ground heat transfer comparison for an uninsulated floor slab with constant interior ambient temperature and variable interior ambient temperature conditions.

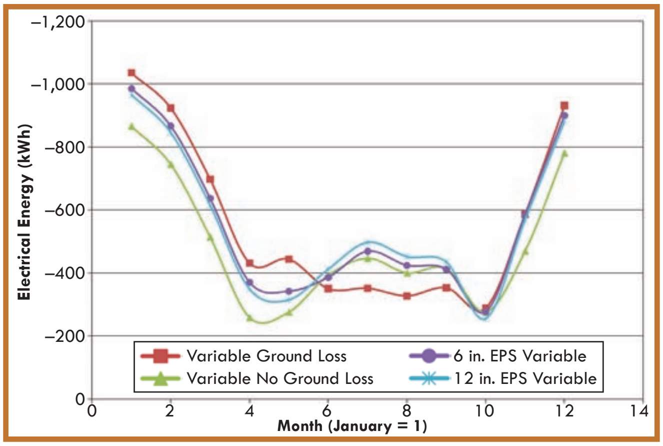

Figure 5: Electrical energy requirements for Equinox with no ground insulation, perfect ground insulation, 6 in. (150 mm) EPS ground insulation, and 12 in. (300 mm) EPS ground insulation.

2.5 W/m^2 (0.79 Btu/h·ft^2). The uninsulated floor with variable interior ambient temperature (Case 3) has ground heat transfer levels that vary by a factor of four, with a significant shift of ground cooling to the summer months.

Figure 5 compares the electrical energy consumption of Equinox House for the varying ambient temperature (Cases 3 to 6); representing the ICF foundation without insulation, a perfectly insulated floor, and the ICF foundation with 150 mm and 300 mm (6 in. and 12 in.) of underslab Styrofoam insulation. The electrical energy requirements include internal energy generation (humans, appliances, etc.), ventilation and infiltration loads, and building shell loads, in addition to the effects of ground heat transfer. Although the temporal variation of ground heat transfer is significant for the different cases, the impact on electrical energy consumption is not so great. The seasonal variation of ground heat transfer shown in *Figure 4* caused by the slight variation of thermostat settings enhances the performance of the earth coupling to the house, minimizing both summer and winter loads in a manner favorable to utilities.

Table 1 also lists the energy demand for the variable interior ambient temperature (Cases 3 to 6) along with the estimated cost and solar panel surface area required for the solar array. The insulation cost is shown in the last column. The cost for perfect insulation (Case 4) is not specified, but given for perspective on the house electrical energy impact. As seen from the results, spending \$5,000 and \$10,000 to insulate 150 mm and 300 mm (6 in. and 12 in.) under the floor reduces overall house electrical energy by 60 and 130 kWh/yr, respectively. In contrast, spending \$1,875 for the ICF foundation reduced electrical energy by 370 kWh/yr. The additional savings in solar system cost due to slab insulation is \$275 and \$550 for Cases 5 and 6. The assumption of a solar system replacement every 20 years favors the insulated foundation wall with no underfloor insulation for our climate.

So, that is why Equinox House has no insulation below the floor. Our results pertain to our region in Central Illinois. Depending on the region, the answer to ground insulation design can change drastically. It is an important question to answer correctly as the design choices can have a great effect on house construction and energy costs.

References

1. Deru, M.P., A.T. Kirkpatrick. 2001. "Ground-Coupled Heat and Moisture Transfer from Buildings; Part 1: Analysis and Modeling." National Renewable Energy Laboratory.
2. Deru, M.P., A.T. Kirkpatrick. 2001. "Ground-Coupled Heat and Moisture Transfer from Buildings; Part 2: Application." National Renewable Energy Laboratory.

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