TOWARDS DETERMINING THE EFFECT OF SHALLOW DEPTH HORIZONTAL GROUND LOOP CLEARANCE ON THE HEAT LOSS OF A SINGLE FAMILY RESIDENTIAL DWELLING

by

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A Major Research Project

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Building Science

in the Program of

Building Science

Toronto, Ontario, Canada, 2018

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Towards Determining the Effect of Shallow Depth Horizontal Ground Loop Clearance on the Heat Loss of a Single Family Residential Dwelling

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Abstract

Using solar energy stored in the ground to preheat incoming fresh ventilation air with ground loops is a renewable energy system which is becoming more frequently used in new residential developments. The purpose of this research was to examine the effect of ground loop to foundation wall clearance on building heat loss. Additionally, the thermal properties of the soil were examined to determine their impact on the ground loop's effect on heat loss. A simulation based research approach was conducted using HEAT3, which is a three-dimensional transient heat transfer software. This study found that ground loop clearance had a larger impact on building heat loss for areas with low thermal conductivity soils than for areas with high thermal conductivity soils. On average, ground loop clearances of 10cm, 50cm, 100cm, and 200cm resulted in increased building heat losses of 20%-83%, 19%-55%, 16%-35%, and 12%-15% respectively.

Acknowledgements

I would first like to thank my research advisor Dr. Richman for his support, guidance, and knowledge. Whether it was meeting at his office, at a coffee shop, or in his home, he always found time to meet with me. I hope he enjoyed this experience as much as I did.

I would also like to thank the gentlemen at PHIUS, Graham Wright and Galen Staengl, for helping me kick off this project in the right direction.

Also, I would like to thank and acknowledge Dr. Berardi for being my second reader and valued professor during my time at Ryerson.

Finally, I must express my profound appreciation to my parents, four siblings, and partner who provided me with continuous support, encouragement, and understanding while I moved half way across the country to pursue my goals. This accomplishment is dedicated to them.

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1 Introduction

Using solar energy stored in the ground to preheat incoming fresh ventilation air with ground loops is a renewable energy system which is becoming more frequently used in new residential developments. The Passive House Institute US (PHIUS) in collaboration with Ryerson University was interested to investigate the effect of ground loop clearance on heat loss from the adjacent building.

Energy in the ground can be used to preheat the ventilation fresh air supply at a relatively low cost. A ground loop preheat system functions by passing a freeze protected fluid through a horizontally buried ground loop to exchange heat with the soil, then passes the fluid through a fluid to air heat exchanger, which preheats incoming ventilation air. The ground loop can be installed in nearly any typical building excavation at various stages of construction since its clearance from foundation walls has traditionally been in the order of 1 m to 2 m. Further, it can be placed under slabs, beside footings, and in other trenches dug for utilities or drainage. A typical system consists of plastic piping, isolation valves, manifold headers, a fluid to air heat exchanger, a fluid circulator, a freeze protected fluid such as a refrigerant, expansion tank, air separator, and other closed-loop system components.

A ground loop preheat system has two main benefits. The first of which is that it eliminates the risk of freezing the core (or filters) of a coupled heat recovery ventilator (HRV) or energy recovery ventilator (ERV). HRVs and ERVs traditionally have in-duct electric resistance preheaters which add considerable operation costs, energy use and installation cost. According to Holladay (2015), using a ground loop system to preheat incoming ventilation air rather than an electric resistance heater leads to an annual savings of 244 kWh to 1315 kWh. Grunau and Craven (2015) found the sensible recovery efficiency (SRE) of a Zehnder ComfoAir 350 dropped from 88% to 49% when using an electric preheater, since the electricity used to preheat the intake air is accounted for in the SRE, which ultimately lowers it. In the case that the HRV or ERV does freeze, the defrost mode of these systems recirculates indoor air and prevents the delivery of fresh air. Therefore, eliminating the risk of freezing in a cost-effective manner is the most beneficial approach. The second benefit of a ground loop preheat system is that it saves energy. The system itself consumes a very low amount of electrical power while the energy used to preheat the incoming ventilation air is “free” energy available in the soil, which is recharged mainly by solar radiation and by the energy stored below buildings that maintains stable soil temperatures.

Typically, horizontal ground loops are buried in a shallow trench at a depth between 1.0m and 2.0m (GeoCom, 2007). These trenches are within soil depths which experience seasonal temperature fluctuations, since daily fluctuations only penetrate within 0.1 m to 0.3 m of depth (Banks, 2008). Soil temperature fluctuations, which are caused by solar radiation, precipitation, and ambient air temperature are predictable and consistent. When a horizontal ground heat exchanger (HGHE) is installed in a heating dominated climate, the seasonal soil temperature distribution can be affected since energy flows from the ground to the ambient exterior for more than half of the year. Removing energy from the ground will decrease soil temperature and increase the temperature difference between the interior space of a building and the surrounding ground, which results in an increase in heat losses. As would be expected, the change in soil temperature caused by ground loops is highest at the soil-ground loop interface, with the effects minimizing as distance from the ground loop increases. To reduce the building heat loss caused by the operation of a ground loop, the loop should be installed as far from the building as possible; however, due to potential spacing constraints during construction, ground loops may need to be installed closer to a foundation wall. As the ground loop comes closer to a foundation wall, the potential exists for increased heat loss from the adjacent building. This effectively short-circuits the renewable aspect of the ground loop and increases energy loss from the building. This research explores the relationship between increased building heat loss, ground loop clearance and soil typology.

1.1 Objectives of the Major Research Project

The main objective of this major research project (MRP) is to better understand the impact that ground loops, at various clearances from the foundation wall, have on a building's heat loss. The secondary objective is to determine how the soil type and associated properties affect the impact that ground loop clearance has on the heat loss of the building. It is anticipated the findings from this research can be used to develop a guideline for prescribing ground loop clearance from foundation walls for the PHIUS+2018 standard. A simulation based approach was used to carry out the research. The analysis considered the impact that the environment and the operation of the ground loop have on the temperature profile of the soil surrounding a building. Once the cause and effect relationship between the independent and dependent variables is determined, then a prescriptive ground loop placement guideline for a wide range of systems can be developed.

1.2 Research Questions

The aim of this research was to determine the building envelope heat losses induced by the operation of a ground loop at various distances from a foundation wall. The two proposed research questions are:

1) What effect does shallow depth horizontal ground loop to foundation wall clearance have on the heat loss of a single family residential dwelling?
2) How do the thermal properties of the surrounding soil affect the shallow depth horizontal ground loop clearance’s impact on the heat loss of a single family residential dwelling?

2 Literature Review

2.1 Development of the Research Questions

A ground loop preheat system is similar to a ground source heat pump (GSHP) system in that it extracts heat from the ground using horizontal ground heat exchangers (HGHE). Rosen and Koohi-Fayegh (2017) published a ground source design textbook which provides guidance for sizing ground loop piping, loop placement, ground loop length, and burial depth. However, details on ground loop placement relative to the building envelope were not provided, possibly because the focus of the HGHE design is to maximize heat transfer of the loop and the problem of additional building heat loss induced by the ground loop may not be obvious. In fact, the Bard Manufacturing Ground Coupled Loop System Design Manual (2007) only specifies loop placement relative to other loops and not the foundation wall. HGHEs function by circulating a lower temperature working fluid, typically a brine solution, through the closed loop piping system, which allows the fluid to extract heat from the ground. If efficiency of the system can be negatively impacted by the reduction of soil temperature, then it is possible that the building's heat loss can be negatively impacted as well.

There has been some research into a HGHE's effect on soil temperature, such as Rosen and Koohi-Fayegh (2017) who observed that HGHE systems installed in soils with high thermal conductivity could result in more significant impacts on the ambient soil temperature. They conducted an experiment on a ground loop system, with the results indicating that after 3 months of operation, the increase in soil temperature due to the ground loops was negligible at distances 10m or greater. After 9 months of operation, the distance increased from 10m to 17m. Temperature sensors were placed adjacent to the HGHE to determine the temperature increase resulting from ground loop operation. After 3 months of operation, the soil temperature was measured to be 0.2 to 0.8 °C higher than the far field soil temperature and after 9 months of operation, the soil temperature was measured to be 1.4 to 2.3 °C higher than the far field soil temperature. Far field soils are similar in composition to the HGHE test soil, but are located at a distance deemed sufficiently far from the temperature changing effects of the HGHE.

Pauli, Neuberger, and Adamovsky (2016) conducted a study with the aim of analyzing temperature changes in the ground caused by a linear and slinky-type HGHE and determining the effect on temperature distribution in the ground. The results showed that the temperature difference between the reference average ground temperature and the HGHE area was 2.22 ± 1.23 °C for the linear HGHE and 3.05 ± 1.41 °C for the slinky-type HGHE. Research has been conducted to determine how soil temperature changes induced by HGHEs can impact the efficiency of the overall GSHP system. In fact, Gonzalez et al. (2012) conducted a year-long study of a horizontal GSHP system located in the UK. The findings indicated that heat extraction can considerably alter soil temperatures and moisture content to the extent that GSHP and any other system using ground loops can have their efficiency be compromised. Continued heat extraction from the ground may cause the soil temperature to fall compared to its 'natural' temperature, which will affect the water and vapor transfer fluxes, thereby influencing the moisture content and thermal properties of the soil, which ultimately affects the performance of the ground loop system. Although this is an important issue, it has already been extensively covered by Li, Yang, and Zhang (2009). If ground loop system efficiency can be negatively impacted by ground heat extraction, then it is probable that a building's heat loss can be negatively impacted too. Gonzalez et al. (2012) showed that the HGHE influenced the soil temperature within 0.6m from the central long axis of a straight HGHE and within 0.8m for a slinky-type HGHE. For soil depths from 0m to 0.2m, the HGHE had negligible effect on ground temperature since air temperature was shown to have a greater effect (Gonzalez et al, 2012). For a depth between 0.25m and 0.3m, the HGHE was shown to have a more measurable effect on soil temperature. In November 2009, the soil temperature near the HGHE was 3° C lower than the reference soil with the temperature difference increasing to 6° C in September 2010 (Gonzalez et al, 2012). At a depth of 1m, which was the burial depth of the HGHE, the temperature influence of the HGHE was observed to reach distances up to 0.9m from the central long axis of the HGHE, which provides further evidence that a HGHE's soil temperature influence could be between 0.6m and 0.9m (Gonzalez et al, 2012).

Researchers have investigated the penalty on GSHP efficiency related to HGHE-induced soil temperature changes, however; there is a lack of research into the effect that these changes in soil temperature would have on a building envelope, such as a basement foundation wall and basement slab. Installing a HGHE far from a building's foundation in order to minimize its effect on nearby soil temperature may seem like a good proposition, but in reality, the horizontal ground loops must often be placed in close proximity to the building envelope due to cost and space constraints. The following four points summarize the current situation:

- Ground loop operation causes the soil temperature to deviate from expected seasonal soil temperature distributions (Gonzalez et al, 2012).
- There is research assessing the impact that soil temperature changes, caused by HGHE operation, have on ground loop system efficiency (Garber-Slaght & Daanen, 2014). However, there is a lack of research into the effect HGHE operation may have on a building's heat loss, possibly because GSHP efficiency can have more of an impact on a building's energy use.

- Soil temperature changes result in a larger temperature difference between the indoor conditioned space and the surrounding soil, which would increase heat losses from the building (Rosenbaum, 2014).
- Locating the ground loop further from the building envelope should reduce the ground loop’s impact on soil temperature near the building envelope, however; typical spacing and cost constraints result in the need for ground loops to be installed near foundation walls (Zheng, Zhang, Liang, & Qian, 2013).

The aim of this research is to determine the additional building heat loss induced by the operation of a ground loop at various distances from a foundation wall.

2.2 Development of the Simulation Methodology and Model

This Section will provide details of the literature which resulted in the development of the methodology outlined in Section 3. The research will use a simulation based approach using HEAT3, a three-dimensional steady-state and transient heat transfer software. The model will be capable of accounting for ground loop operation, environmental conditions, building envelope, and soil properties.

A simplified numerical and analytical model was utilized by Selamat, Miyara, and Kariya (2016) to optimize several different HGHE design arrangements. It used 3D CFD models to carry out the analysis. Some of the simplifications included: the pipe wall modeled having zero thickness thus generated by the CFD solving process, a temperature boundary condition with a varying heat flux was imposed on the surface, adiabatic boundary conditions were applied to all four far field boundaries, and the bottom boundary had a geothermal heat flux of 65 mW/m^2 assigned. The geothermal heat flux boundary condition will be similar to a constant temperature boundary condition since deep soil temperatures are predictable and constant. It was later observed that the heat flow from the HGHE did not exceed 0.8m nor did it reach either the far field boundaries or the bottom boundary. However, it was noted by Rosen and Koohi-Fayegh (2017) that soil temperature effects of the HGHE was observed up to 17m away from the source, which is why the model used in this currently discussed research has far-field boundaries up to 30m away. Selamat, Miyara, and Kariya (2016) noted that the simplified model would penalize the accuracy of the CFD solution, however; the approach would be adequate in providing a comparison between the various test cases. This MRP will use a simplified analytical approach since the model should be sufficiently accurate when used as a comparative tool.

3 Methodology

The software used to conduct the simulations detailed in this research was HEAT3, which is a three-dimensional steady-state and transient heat transfer software. HEAT3 was selected over other software such as TRNSYS (www.trnsys.com), ANSYS Fluent (www.ansys.com/Products/Fluids/ANSYS-Fluent), and GLD (Ground Loop Design) [www.groundloopdesign.com] for a variety of reasons. ANSYS Fluent focuses more on the fluid behavior within the ground loop, which was not of interest in this research. GLD, TRNSYS, and other GSHP design software were not selected because these programs focus on the ground loop design aspect, including number of loops, loop configurations (slinky versus horizontal), loop placement, and pipe size. These specialized programs are used to size the equipment of the system to meet a specified heating load. The main advantage of HEAT3 is that it’s a generalist software which allows the whole system to be evaluated, and it allowed for the monitoring of building heat loss to be focused on. The ground loop heat flux was calculated using the method outlined in Section 3.2.3, which is all a GSHP design software would have been needed for in this specific application.

3.1 Experimental Variables to Consider

The four major components of the overall system which affect or are affected by soil temperature are the environment, soil type, ground loop, and building enclosure. The system is affected by the individual parameters of each component. In general, the environment and ground loop affect the soil temperature, which in turn affects the building's heat loss or gains. Several important environmental variables that impact soil temperature were presented by Gonzalez et al. (2012) who attributed natural shallow (less than 3m depth) soil temperature variations to incident solar radiation, fluctuations in air temperature, type and density of vegetative cover, and rainfall. Gonzalez et al. (2012) discovered that vegetation growth in the spring could result in a soil temperature difference of 2° C between soil with and without vegetation growth. This was re-affirmed by Pauli, Neuberger, and Adamovsky (2016) who determined that environmental conditions such as solar radiation intensity and daytime and nighttime radiation heat exchange between the Earth's surface and the sky played an important role on shallow soil temperatures. Further additional findings by Hepburn, Sedighi, Thomas, and Manju (2016) attributed soil temperature variations to the ambient environment's relative humidity and wind speed.

A review of the literature indicated that soil properties have the biggest impact on the thermal response of the soil. Gonzalez et al. (2012) showed that variations in soil temperature are a function of soil textural composition (i.e. proportions of sand, clay, and silt) and soil thermal properties such as heat capacity, thermal conductivity, and heat diffusivity. Further, the moisture content of the soil, which is determined by rainfall, evapotranspiration, and soil hydraulic properties (i.e. properties affecting infiltration, drainage, and runoff) will also exhibit a strong effect on the soil's thermal properties. In addition, Hepburn, Sedighi, Thomas, and Manju (2016) attributed a soil's temperature profile to soil density, porosity, and saturated hydraulic conductivity. An experimental test performed by Neuberger, Adamovsky, and Sed'ova (2014) showed that the primary variable affecting the heat transfer in a soil was the thermal conductivity of the soil. The test also showed that thermal conductivity was most affected by moisture content. The tested thermal conductivities for a dry soil, regular soil, and wet soil were 0.6 W/m•K, 2.3 W/m•K, and 2.7 W/m•K respectively. Frozen soils were shown to have a higher thermal conductivity than soils above 0 °C, with results showing that frozen clay soil had a thermal conductivity of 2.454 W/m•K compared to 1.616 W/m•K for clay soil above 0 °C.

The overall heat transfer from the ground, which will affect soil temperature, is also influenced by the characteristics of the ground loop. Selamat, Miyara, and Kariya (2016) have shown that higher rates of heat transfer occur with slinky-type loops compared to straight horizontal loops due to increased contact area and turbulent fluid flow. In addition, Hepburn, Sedighi, Thomas, and Manju (2016) showed that system flow rate and specific heat capacity of the working fluid would also influence the heat transfer of the system. Other variables proven to affect the heat transfer of the system are ground loop pipe diameter, length of piping, burial depth of pipe, spacing of the loops, working fluid density, and working fluid thermal conductivity, per findings by Neuberger, Adamovsky, and Sed'ova (2014).

The final set of variables that must be considered are related to the building. The soil temperatures and distributions must be used in conjunction with details of the building envelope and conditioned space in order to determine the ground loop's impact on building heat loss. Details to consider are the envelope details and construction (i.e. type of insulation), and material properties such as thickness, thermal conductivity, resistance, specific heat capacity, and vapor permeability. A summary of all the variables presented in this Section are listed in Table 1.

Table 1: Experimental variables affecting or affected by soil temperature

Environmental Variables	Soil Variables	Ground Loop Variables	Building Variables
• Solar radiation • Air temperature • Type and density of vegetative cover • Rainfall • Windspeed • Relative humidity • Radiation exchange between the surface and sky	• Soil textural composition • Heat capacity • Thermal conductivity • Heat diffusivity • Thermal resistance • Moisture content • Density • Porosity • Saturated hydraulic conductivity	• Slinky or straight configuration • Fluid flow rate • Fluid specific heat capacity • Fluid thermal conductivity • Fluid density • Pipe diameter • Pipe thermal conductivity • Length of pipe • Burial depth of pipe	• Assembly details • Indoor conditions • Insulation type • Material thicknesses • Material specific heat capacity • Material vapor permeability

As previously stated, the primary variable affecting heat transfer in the soil is the soil's thermal conductivity. The proposed research is not an investigation into how the various soil properties affect thermal conductivity, therefore, if the thermal conductivity of the soil is known, then knowing all other soil properties becomes less pertinent. For the environmental variables, solar radiation and air temperature are expected to be the main influencers of shallow depth ground temperature. Radiation exchange between the surface and sky could also have an impactful role. It is important to simplify the soil model as they can become quite complex. For the ground loop variables, it is expected that fluid flow rate, heat capacity, fluid temperature, and thermal conductivity will play the biggest role in determining the heat transfer of the system, and all ground loop variables listed in Table 1 should be considered. However, as will be shown in Section 3.2.3, the ground loop heat flux can be calculated using manufacturer provided data and specifications. As the research will focus on the impact to heat losses through the building envelope, all the building variables listed in Table 1 should be considered.

HEAT3, a three-dimensional steady-state and transient heat transfer software, was used to conduct the simulations detailed in this research. The typical building typology for PHIUS is the single family detached home, which is what has driven the major simulation parameters of this research. As preheat ventilation air was the focus, Duluth, MN was selected as it is in climate zone

7. The three main components comprising the research methodology were the development of the model and inputs, testing of the model, and execution of the simulations. These components are discussed in further detail in Sections 3.2 to 3.4. The following Sections will refer to sides 1&2, 3&4, and 5 of the building. They are defined in Figure 1.

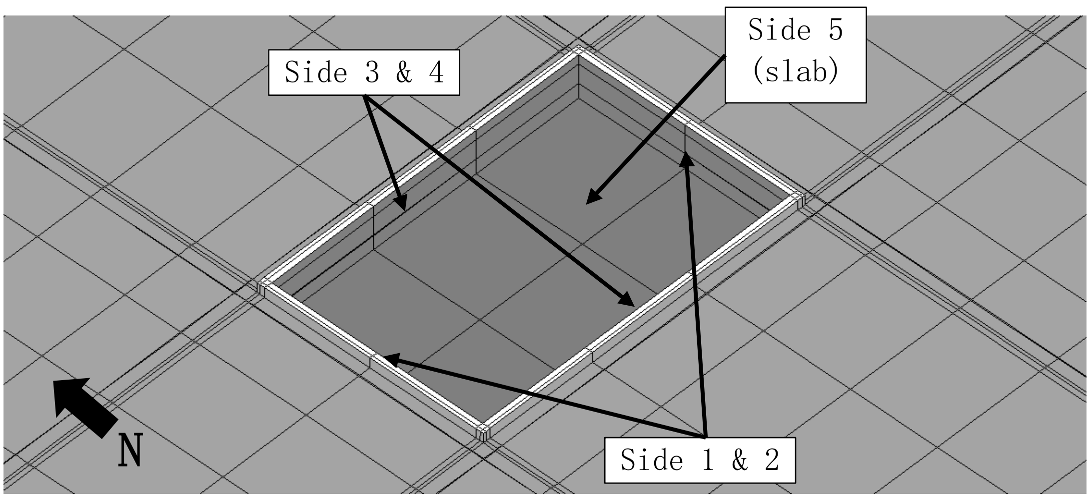


Figure 1: Interior surface identifiers

3.2 Development of the Model

The model was developed by understanding and selecting the input parameters required by the software, namely, the physical layout and geometry, the material and soil properties, expected ground loop heat fluxes, and boundary conditions.

3.2.1 Model Geometry and Layout

As this research was of interest to PHIUS, many parameters, including the model geometry and layout were influenced by their main typology, the single family detached house. The model excluded everything form the building except the basement foundation since the research focused on the interaction between the soil and the basement foundation walls. An exterior building footprint of 10m x 15m (150m^2), equivalent to 134m^2 of interior floor space was selected as this represents an average sized home in the United States (Perry, 2014). The building typology was selected to be a house with a basement foundation (rather than slab on grade) as changes in soil temperature would have the greatest thermal impact on this typology. The PHIUS recommended R-value of basement foundation walls in climate zone 7 is R-30, therefore, at R-5/inch, the thickness of the exterior insulation was set to 6 inches. The thickness of the concrete foundation walls was set to 8 inches, in line with typical foundation wall thickness requirements (FEMA, 2006). Finally, the interior ceiling height of the basement was set to 9 feet.

With the physical dimensions of the building established, the next component of the model's geometry to be determined was the size of the surrounding land, which will be referred to as the test plot. Selamat, Miyara, and Kariya (2016) developed an analytical simulation model with a test plot size of 10m length x 10m width which allowed for the safe assumption that the temperature on the far-field boundaries would have no effect on the ground heat exchanger. The depth of their test plot was set to 5m since at this distance, the temperature can be assumed to be constant for short time analysis. After consultation with industry experts and the findings presented in Section 2.2, it was decided that the test plot size for this research was to be increased to 75m long x 70m wide x 15m deep, which greatly exceeds the size used by Selamat, Miyara, and Kariya (2016). The larger test plot size provides additional assurance that assuming adiabatic conditions at the far-field boundaries is valid. Also, it has been shown that the ground temperature is constant at depths below 9m (Reysa, 2015). The test plot assumed there are no adjacent buildings nearby. Figure 2 and Figure 3 present the three main materials in the HEAT3 model, which are concrete (dark grey), soil (medium grey), and EPS insulation (light grey).

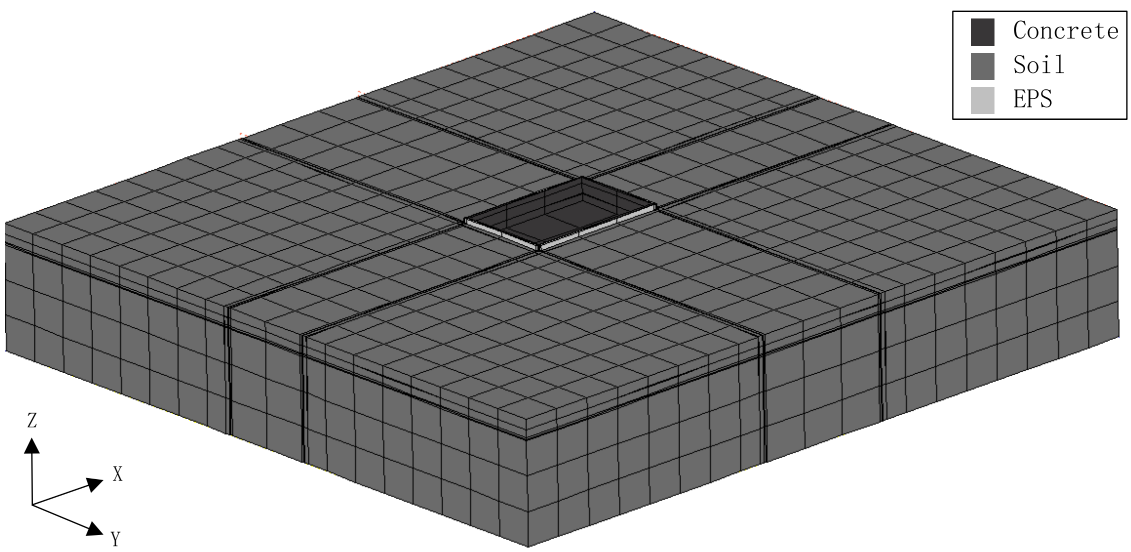


Figure 2: HEAT3 model material types [1 of 2]

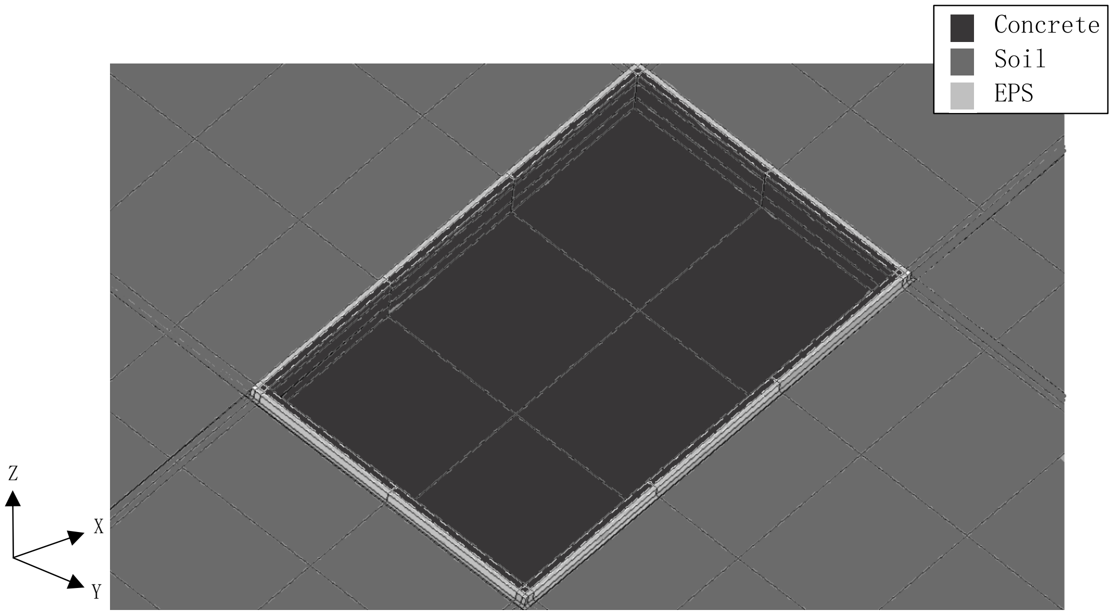


Figure 3: HEAT3 model material types [2 of 2]

The geometric dimensions, in meters, of the test plot and building are shown in Figure 4 (plan view) and Figure 5 (elevation view).

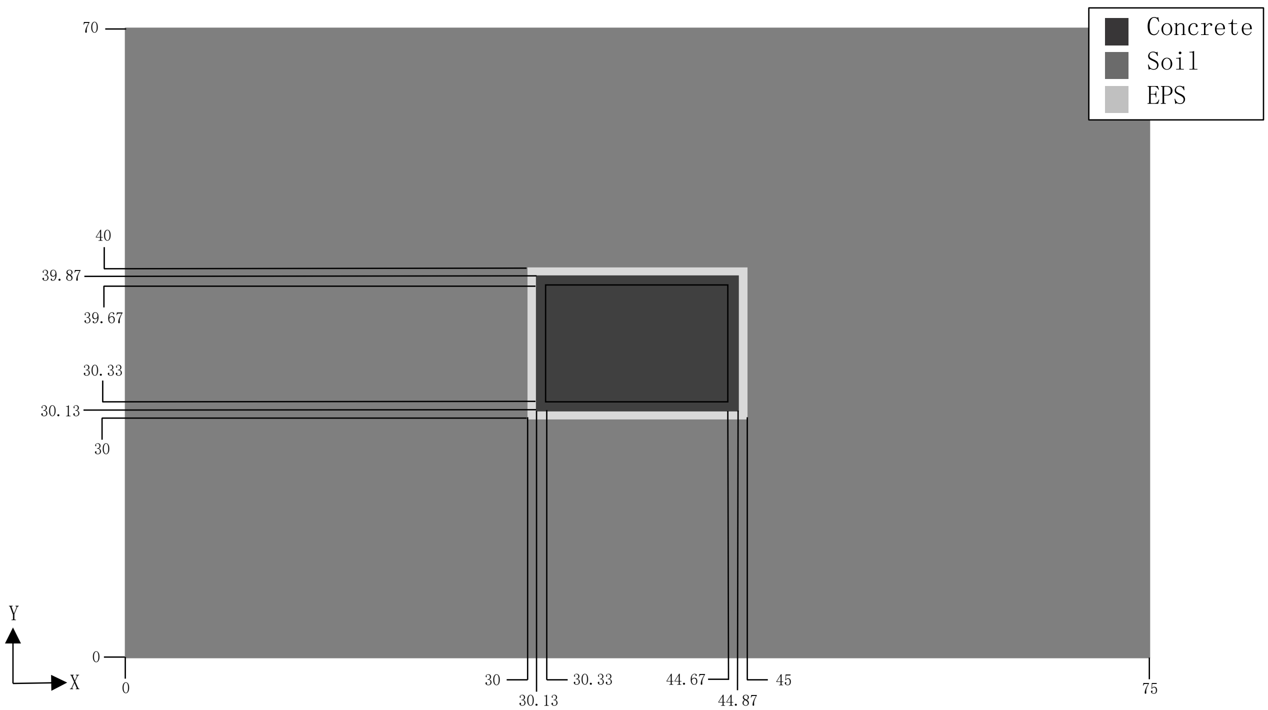


Figure 4: Geometric dimensions of HEAT3 model [plan view]

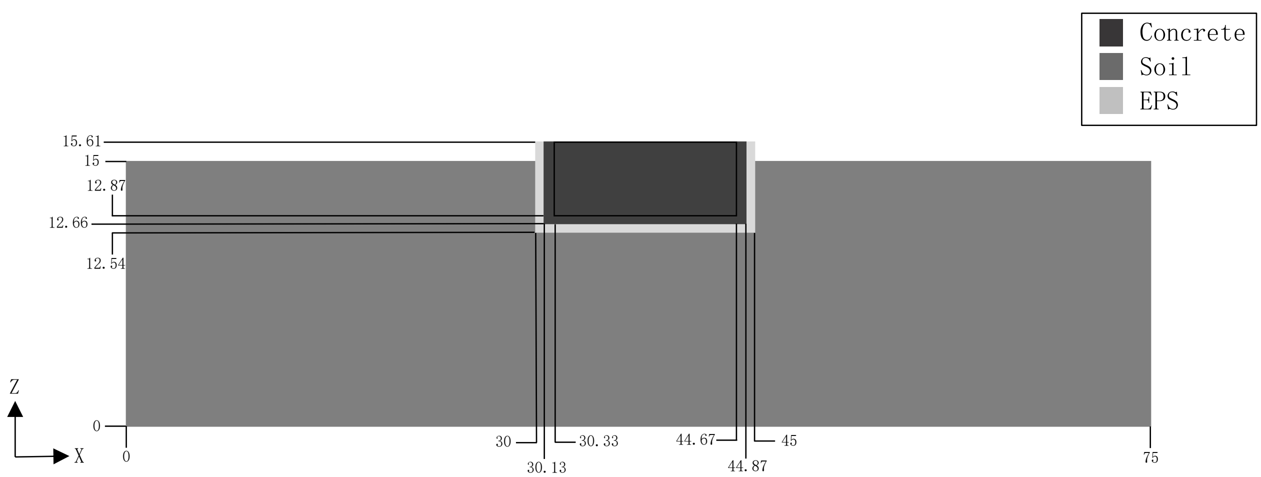


Figure 5: Geometric dimensions of HEAT3 model [elevation view]

The brine geothermal heat exchanger equipment selected for this research was the Zehnder ComfoFond-L Eco 350 (data sheet provided in Appendix 7.1). This specific model was selected because it is suitable for residential applications, is compatible with other Zehnder ERVs, and can be used in a variety of soil types such as sand, silt, loam, and clay. The relevant ground loop input parameters associated with the Zehnder ComfoFond-L Eco 350 specifications provided by the manufacturer are the following: pipe diameter of 3/4″, single loop, and a burial depth of 1.2m (4 ft). After consultation with members of the PHIUS technical committee, it was agreed upon that based on their professional experience, a ground loop installation clearance of up to 200cm was typical. Therefore, to encompass a broad range of potential installations, the ground loop clearances, measured from edge of pipe to exterior insulation, were selected to be 10cm, 50cm, 100cm, and 200cm.

3.2.2 Material Properties

The relevant input parameters for the concrete foundation and EPS insulation used in the simulation are provided in Table 2. The properties were retrieved from data provided by Hutcheon and Handegord (1995) as well as from the Owens Corning FOAMULAR® 150 product data sheet (provided in Appendix 7.2).

Table 2: Material property inputs for HEAT3

Material Name	Thermal Conductivity, k [W/(m•K)]	Density, ρ [kg/m^3]	Specific Heat Capacity, c [J/kg•K]	Volumetric Heat Capacity, VHC [MJ/m^3•K]
Concrete	1.32	2250	750	1.69
EPS	0.036	29	1500	0.044

HEAT3 requires the input of the volumetric heat capacity (VHC), which is the product between density and specific heat capacity. To decrease computation time and the overall length of this MRP, the number of simulation variables were reduced. To do so, only one set of typical properties for the concrete and EPS were selected, however, this was not the case for the soil properties. The comprehensive list of soil properties shown in Table 3 was data provided by Hamdhan and Clarke (2010). As observed, the soils have a broad range of densities (1390 to 2369 kg/m^3), thermal conductivities (0.15 to 5.03 W/m•K), specific heat capacities (800 to 2646 J/kg•K), and volumetric heat capacities (1.11 to 4.37 MJ/m^3•K).

Table 3: Soil properties

Soil Type	Bulk Density, ρ [kg/m^3]	Thermal Conductivity, k [W/(m•K)]	Specific Heat Capacity, c [J/(kg•K)]	Volumetric Heat Capacity, VHC [MJ/(m^3•K)]
Fine Sand (Dry)	1600	0.15	800	1.28
China Clay (Dry)	1390	0.25	800	1.11
Course Sand (Dry)	1800	0.25	800	1.44
Medium Sand (Dry)	1700	0.27	800	1.36
China Clay (Sat.)	1730	1.52	2362	4.09
Sandy Clay 1	1890	1.61	1696	3.21
Sandy Clay 2	2100	2.45	1459	3.06
Fine Sand (Sat.)	2010	2.75	1632	3.28
Soft Grey Fine Sandy Clay	1741	3.03	2200	3.83
Stiff Grey Brown Sandy Gravelly Clay	2352	3.2	1104	2.6
Stiff Dark Grey Sandy Gravelly Clay	2369	3.28	1125	2.67
Medium Sand (Sat.)	2080	3.34	1483	3.08
Very Soft Grey Fine Sandy Clay	1711	3.51	2362	4.04
Soft Dark Grey Sandy Gravelly Clay	1912	3.57	1764	3.37
Stiff Dark Grey Sandy Gravelly Clay	2299	3.69	1141	2.62
Course Sand (Sat.)	2080	3.72	1483	3.08
Soft Grey Fine Sandy Clay	1650	4.2	2646	4.37
Dark Grey Clayey Fine Sand Silt	1848	4.26	1747	3.23

Soil Type	Bulk Density, ρ [kg/m³]	Thermal Conductivity, k [W/(m•K)]	Specific Heat Capacity, c [J/kg•K]	Volumetric Heat Capacity, VHC [MJ/m³•K]
Grey Slightly Silty Sandy Gravel	1983	4.44	1175	2.33
Made Ground, Silty Gravelly Sand	2182	5.03	1270	2.77

The typical soil found in the Superior Area of Minnesota is composed of lacustrine deposits of silt and clay (Caine & Lyman, 1904). There are numerous streams flowing directly north into Lake Superior and the Nemadji River (Caine & Lyman, 1904). The number of streams combined with the agricultural potential of the soil would suggest the clay has relatively high moisture content, indicating it would have a high thermal conductivity soil. However, after the testing performed in Section 3.3.3 demonstrated that the building’s heat loss greatly depends on the properties of the surrounding soil, it was decided that five soil types covering a broad range of soil properties be used in the analysis to ensure a more complete picture of the results was captured. Five discrete soil properties were selected from Table 3, covering a broad range of thermal conductivities and volumetric heat capacities. The soils covered the following ranges: soil 1 (low thermal conductivity, low volumetric heat capacity), soil 2 (high thermal conductivity, high volumetric heat capacity), soil 3 (low thermal conductivity, high volumetric heat capacity), soil 4 (high thermal conductivity, low volumetric heat capacity), and soil 5 (average thermal conductivity, average volumetric heat capacity). By using five soils to cover a range of parameters, the number of variables and hence simulation time was greatly reduced. The soil properties used in this analysis that are provided in Table 4, were sourced from Table 3. Since the analysis was limited by five soil types, it was more beneficial to select soil properties based on actual results rather than a linear approach to allow for a greater diversity of soil properties to be tested in the analysis. Although Soil 1 and 3 were selected to have low thermal conductivities, it was only Soil 1 with a thermal conductivity of 0.25 W/(m•k), which showed the most observable trends. If Soil 1 and Soil 3 both had a thermal conductivity of 1.52 W/(m•k) rather than 0.25 W/(m•k), then the trends observed would have led to different or weaker conclusions. The drawback of the using actual soil results instead of a more linear approach is that the effect of volumetric heat capacity couldn't be fairly compared. If Soil 1 and 3 had the same thermal conductivity, but two different volumetric heat capacities, then the effect of varying volumetric heat capacity could accurately be compared.

Table 4: HEAT3 soil properties

Soil Number	Thermal Conductivity, k [W/(m•K)]	Volumetric Heat Capacity, VHC [MJ/m^3•K]
Soil 1	0.25	1.36
Soil 2	4.44	4.04
Soil 3	1.52	3.83
Soil 4	4.20	1.46
Soil 5	2.73	2.84

3.2.3 Ground Loop Heat Flux

This Section details the methodology used to estimate the ground loop heat flux based on the outside air temperature. The relevant specifications for the geothermal recovery unit used in this research are summarized in Table 5 (data sheet is provided in Appendix 7.1).

Table 5: Zehnder ComfoFond-L Eco 350 specifications

Operating Temperature	-22° C to +45° C
Pre-Heat Capacity	+1864 W
Pre-Cool Capacity	-1961 W
Flow Rate	8 L/min

The manufacturer's data sheet also provided two sample operating cases of the geothermal recovery unit (GRU), which provided the information required to calculate the heat transfer rate under those specific conditions. The two sample operating cases provided in addition to the density and specific heat capacity of air at the corresponding conditions are presented in Table 6.

Table 6: Sample operating case conditions provided by manufacturer

Condition	Summer	Winter
Supply Air Temperature	17 ° C	6.5 ° C
Outside Air Temperature	35 ° C	-12 ° C
Airflow Rate	250 m^3/hr	250 m^3/hr
Specific Heat Capacity	0.718 kJ/(kg•K)	0.718 kJ/(kg•K)
Density	1.15 kg/m^3 @ 35 ° C	1.34 kg/m^3 @ -10 ° C

The heat transfer rate was calculated using the following equation:

$$Q = \dot{m} c \Delta T \qquad [1]$$

Where, Q = heat transfer rate [W]

$\dot{m}$ = mass flow rate of air [kg/s]

c = specific heat capacity of air [J/(kg•K)]

ΔT = temperature difference of supply and outside air [°C]

The heat fluxes for the summer and winter operating cases were calculated to be 1028 W and -1237 W respectively. It was assumed that the maximum pre-cool capacity of 1864 W was for the maximum GRU operating temperature of +45 °C and that the maximum pre-heat capacity of -1961 W was for the minimum GRU operating temperature of -22 °C. These four heat fluxes and outdoor air temperatures were used to interpolate the supply air temperatures corresponding to outdoor air temperatures within the -22 °C to +45 °C operating range of the GRU. The temperature difference between the outside air temperature and interpolated supply air temperature, along with the mass flow rate and specific heat capacity of air were used to calculate the heat fluxes of the ground loop at various outside air temperatures. The calculated heat fluxes are shown in Table 7.

Table 7: Interpolated ground loop heat flux at various outside air temperatures

Parameter	A	B	C	D	E	F	G	H
Heat Flux [W]	**1961**	1495	**1028**	787	546	305	64	-177
Supply Air Temperature [° C]	19.9	21.0	**17**	20.3	18.4	16.4	14.2	12.0
Outside Air Temperature [° C]	**45**	40	**35**	30	25	20	15	10
ΔT[° C]	25.1	19.0	18	9.7	6.6	3.6	0.8	-2.0
Air Density [kg/m^3]	1.118	1.127	1.1455	1.1644	1.1839	1.2041	1.225	1.2466
Parameter	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
Heat Flux [W]	-418	-659	-900	-1141	**-1237**	-1425	-1739	**-1864**
Supply Air Temperature [° C]	9.7	7.3	4.8	2.2	**6.5**	0.0	-2.1	-3.2
Outside Air Temperature [° C]	5	0	-5	-10	**-12**	-15	-20	**-22**
ΔT[° C]	-4.7	-7.3	-9.8	-12.2	-18.5	-15.0	-17.9	-18.8
Air Density [kg/m^3]	1.269	1.2922	1.3163	1.3413	1.3413	1.3673	1.3943	1.4224

To summarize, the bolded values in columns, A, C, M, and P of Table 7 were provided by the manufacturer and subsequently used to interpolate all other values in the Table. The outside air temperature was chosen at 5 ° C increments between the -22 ° C to +45 ° C operating range of the GRU. Columns A and C were used to interpolate column B, columns C and M were used to interpolate columns D to L, and columns M and P were used to interpolate columns N and O. To calculate the ground loop heat flux, Equation 1 was used along with the interpolated supply air temperature and assumed air flow rate of 250 m^3/hr.

3.2.4 Boundary Conditions

The model contains the following three types of boundary conditions: imposed temperature (allows for temperature variance over time), constant temperature (constant with time), and adiabatic (no heat transfer). These three types of boundary conditions were applied to the model as follows:

1) The test plot's four far field boundaries and building's basement foundation wall to first floor wall interface had adiabatic boundary conditions applied. This assumed no other heat sources or sinks were within an appreciable distance to affect the results.
2) The interior walls and floor of the building had a constant temperature boundary condition of 21° C applied.
3) The test plot's bottom boundary had a constant temperature boundary condition of 3.9° C applied, which is the temperature of the soil at a depth of 30 feet in Duluth, MN (Reysa, 2015).
4) The test plot's top boundary, the soil to air interface, had an imposed temperature boundary condition applied. The boundary condition used the TMY2 climate data file for Duluth, MN which allowed for the temperature to vary throughout the year on a daily basis. This assumed that the temperature at the soil's surface was the same as the outside air temperature.

The applied boundary conditions are shown in Figure 6 to Figure 8.

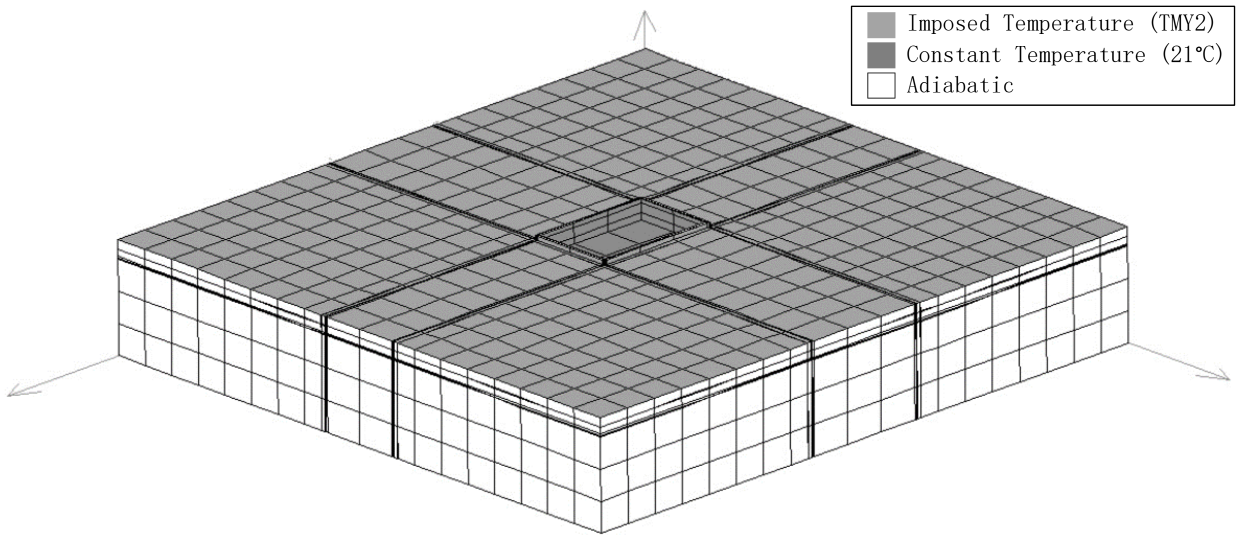


Figure 6: HEAT 3 boundary conditions [1 of 3]

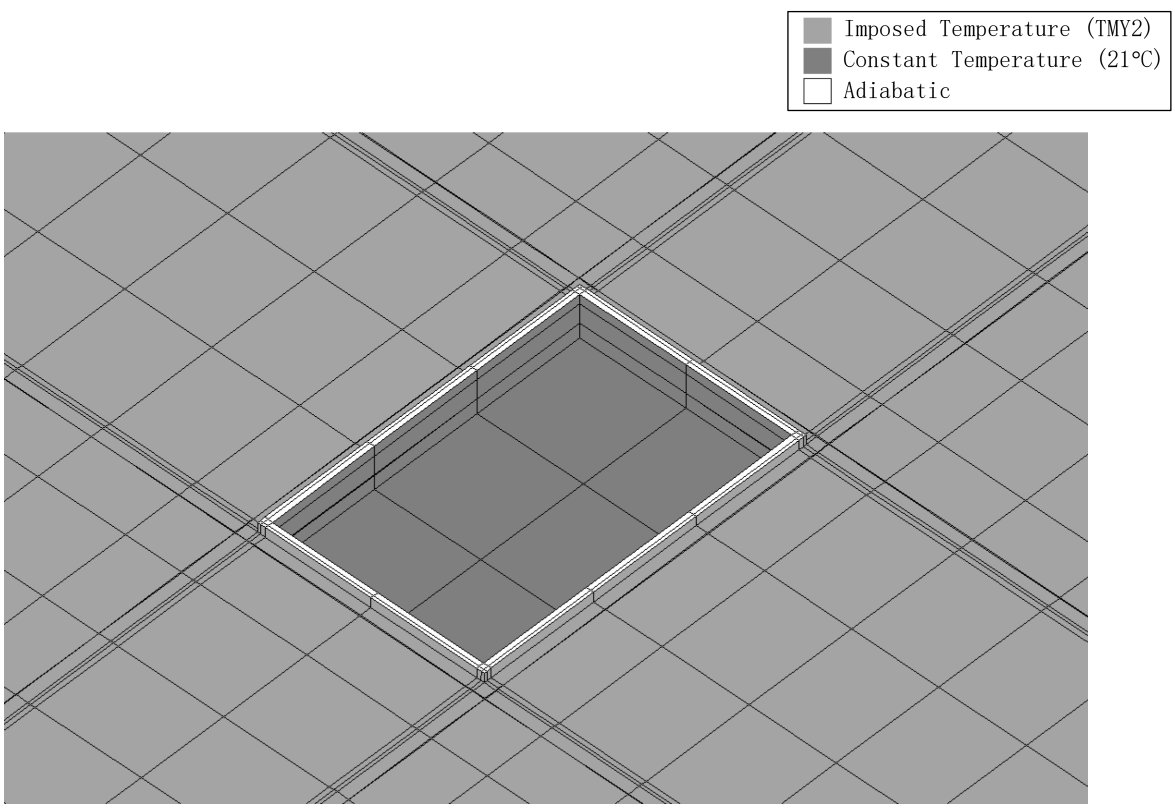


Figure 7: HEAT 3 boundary conditions [2 of 3]

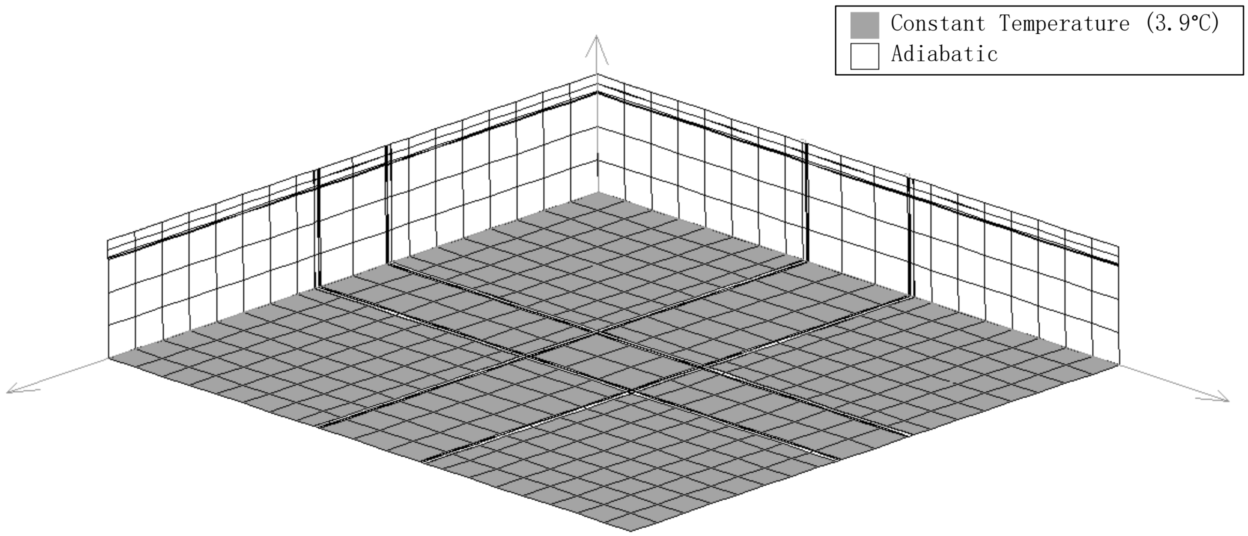


Figure 8: HEAT 3 boundary conditions [3 of 3]

3.3 Testing of the Model

The completed HEAT3 model was subjected to various tests to determine when steady state would be reached, what mesh size was optimal, and if multiple soil types were necessary.

3.3.1 Steady State Testing

The HEAT3 model was tested to determine when steady state soil temperatures would be reached for two cases: test site without a ground loop and test site with a ground loop. To ensure the analysis produced reliable results, it was important to first reach steady state without the ground loop, then to reach steady state again with the ground loop. Table 8 shows the heat loss of sides 1 to 5 for the test site without the influence of a ground loop. As can be observed, the change in heat loss is essentially 0% between years 14 and 15. This indicates that steady state soil temperatures are reached by year 15.

Table 8: Side 1 to 5 heat loss without the effect of a ground loop

Year	Side 1 Heat Loss [W]	Change from Previous Year [%]	Side 2 Heat Loss [W]	Change from Previous Year [%]	Side 3 Heat Loss [W]	Change from Previous Year [%]	Side 4 Heat Loss [W]	Change from Previous Year [%]	Side 5 Heat Loss [W]	Change from Previous Year [%]
1	131.90	-	131.90	-	199.67	-	199.67	-	378.92	
2	130.33	1.20	130.33	1.20	197.19	1.26	197.19	1.26	345.78	9.58
3	129.44	0.69	129.44	0.69	195.78	0.72	195.78	0.72	327.37	5.62
4	128.92	0.40	128.92	0.40	194.96	0.42	194.96	0.42	316.71	3.37
5	128.61	0.24	128.61	0.24	194.48	0.25	194.48	0.25	310.49	2.00
6	128.44	0.13	128.44	0.13	194.20	0.14	194.20	0.14	306.86	1.18
7	128.33	0.09	128.33	0.09	194.03	0.09	194.03	0.09	304.73	0.70
8	128.27	0.05	128.27	0.05	193.93	0.05	193.93	0.05	303.48	0.41
9	128.23	0.03	128.23	0.03	193.88	0.03	193.88	0.03	302.75	0.24
10	128.21	0.02	128.21	0.02	193.84	0.02	193.84	0.02	302.32	0.14
11	128.20	0.01	128.20	0.01	193.83	0.01	193.83	0.01	302.07	0.08
12	128.19	0.01	128.19	0.01	193.81	0.01	193.81	0.01	301.93	0.05
13	128.19	0.00	128.19	0.00	193.81	0.00	193.81	0.00	301.84	0.03
14	128.19	0.00	128.19	0.00	193.80	0.01	193.80	0.01	301.79	0.02
15	128.19	0.00	128.19	0.00	193.80	0.00	193.80	0.00	301.76	0.01

Table 9 shows the heat loss of side 1 to 5 for the test site with the influence of a ground loop. According to NPARC (2008), iterative convergence can be considered to have occurred when the results begin to converge. The convergence criteria is defined by acceptable error in these values, which should be selected by the user (NPARC, 2008). As can be observed in Table 9, the change in heat loss is less than 5% between years 4 and 5. Based on the nature of this analysis, this author has deemed that using an acceptable error of 5% will provide sufficient accuracy in the results. Assuming the ground loop heat flux does not vary year to year, then steady state soil temperatures will be reached by year 5.

Table 9: Side 1 to 5 heat loss with the effect of a ground loop

Year	Side 1 Heat Loss [W]	Change from Previous Year [%]	Side 2 Heat Loss [W]	Change from Previous Year [%]	Side 3 Heat Loss [W]	Change from Previous Year [%]	Side 4 Heat Loss [W]	Change from Previous Year [%]	Side 5 Heat Loss [W]	Change from Previous Year [%]
1	-16.07	-	-16.07	-	-1.89	-	-1.89	-	159.00	-
2	-10.87	47.87	-10.87	47.87	4.18	-145.30	4.18	-145.30	189.10	-15.92
3	-9.94	9.33	-9.94	9.33	5.37	-22.26	5.37	-22.26	200.25	-5.57
4	-9.54	4.16	-9.54	4.16	5.92	-9.27	5.92	-9.27	206.14	-2.86
5	-9.32	2.37	-9.32	2.37	6.18	-4.21	6.18	-4.21	209.72	-1.71

3.3.2 Mesh Size Optimization

In HEAT3, the numerical mesh can be automatically generated by specifying the number of computational cells per element, N_i. The computational cell count can vary from a minimum of N_i = 20 to a maximum of N_i = 130. The number of computational cells are applied in an equidistant manner in each direction of the element. Like other finite element software, smaller mesh sizes (i.e. a higher number of computational cells) will result in more accurate results as well as longer computation times. The purpose of the testing in this section was to determine the minimum amount of computation cells per element that would provide sufficiently accurate results, thereby avoiding unnecessary computational load. As observed in Table 10, the percent change in results from N_i = 80 to N_i = 100 is less than 1%, which indicated that a cell count larger than N_i = 100 was not necessary.

Table 10: Mesh size optimization results

Cell Count [N_i]	20			40			60			80			100		
Side #	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
Heat Loss [W]	199.2	302.4	407.0	196.1	298.7	429.2	195.3	295.8	442.3	195.9	296.2	451.3	195.5	296.0	455.5
Change from Previous [%]	-	-	-	1.53	1.24	5.45	0.44	0.95	3.04	0.35	0.14	2.06	0.21	0.08	0.93
Computation Time	1min 5s			3min			6min 36s			14min			30min		

3.3.3 Soil Properties Sensitivity Test

The two soil properties that must be input into the HEAT3 model are thermal conductivity and volumetric heat capacity (i.e. the product of the density and specific heat capacity). This soil test was conducted to determine if using one soil type in the analysis would be satisfactory in providing sufficient result quality. As there are countless different soil types and combinations of soil types, it was important to reduce the number of soils used in the analysis to decrease computation time. Table 11 provides the input parameters of eight test soils, which were used to determine how much variance in the results they would cause.

Table 11: Test soil properties

Soil Number	Thermal Conductivity, k [W/(m•K)]	Volumetric Heat Capacity, VHC [MJ/m^3•K]
Test Soil 1	0.50	3.00
Test Soil 2	1.50	3.00
Test Soil 3	3.00	3.00
Test Soil 4	4.50	3.00
Test Soil 5	2.60	1.00
Test Soil 6	2.60	2.00
Test Soil 7	2.60	3.00
Test Soil 8	2.60	4.00

Eight simulations were run while holding all parameters constant except the soil type. The minimum and maximum heat losses of side 1 of the building over a 15-year simulation period are presented in Table 12. The maximum heat loss observed ranged from 153.5 W to 246.5 W and the minimum heat loss observed ranged from 23.8 W to 36.5 W. The large variance in results showed that soil type can have a significant impact on the heat loss of the building, which is why the decision was made to use five soil types to cover the following ranges in the analysis: soil 1 (low thermal conductivity, low volumetric heat capacity), soil 2 (high thermal conductivity, high volumetric heat capacity), soil 3 (low thermal conductivity, high volumetric heat capacity), soil 4 (high thermal conductivity, low volumetric heat capacity), and soil 5 (average thermal conductivity, average volumetric heat capacity).

Table 12: Minimum and maximum building heat loss using test soils 1 to 8

Soil Type	Test Soil 1	Test Soil 2	Test Soil 3	Test Soil 4	Test Soil 5	Test Soil 6	Test Soil 7	Test Soil 8
Minimum Heat Loss [W]	33.6	34.1	33.7	32.8	23.8	30.4	33.8	36.5
Maximum Heat Loss [W]	153.5	203.9	229.7	242.2	246.5	232.8	224.8	219.2

Test soils 1 to 4 had thermal conductivity varied while holding the volumetric heat capacity constant while test soils 5 to 8 had thermal conductivity held constant and volumetric heat capacity varied. As observed in Table 12, there is more variance in the maximum heat losses for test soils 1 to 4 compared to test soils 5 to 8, indicating that thermal conductivity has a bigger impact on heat loss than volumetric heat capacity. This resulted in the research focusing on the effect of thermal conductivity rather than volumetric heat capacity.

3.4 Simulation Methodology

The final component comprising the overall research methodology was the simulation methodology. Figure 9 provides an overall summary of the main variables for the simulations.

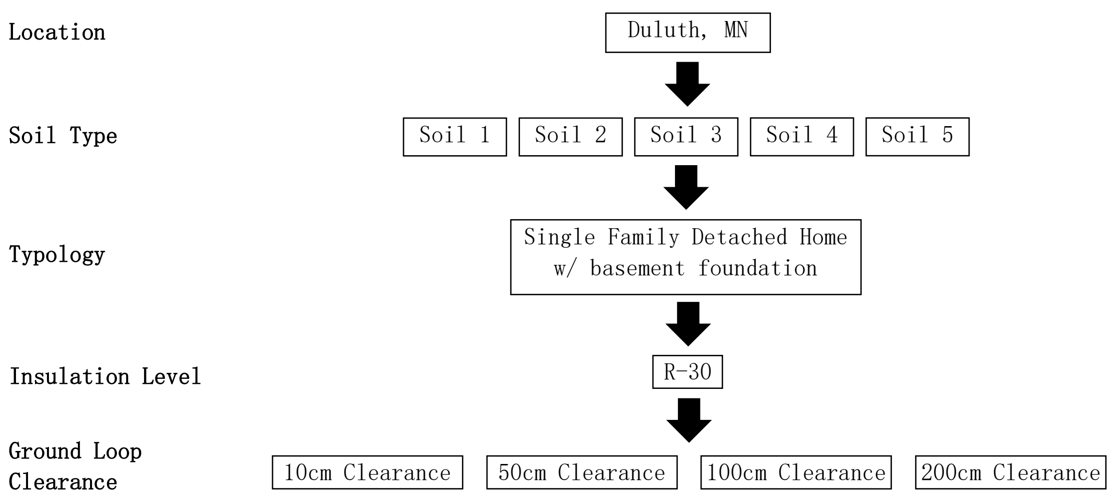


Figure 9: Manipulated and fixed variables in the analysis

The control variables include the location (Duluth, MN), building typology (average sized single family detached home with basement foundation), and basement insulation (EPS, R-30). The independent variables are the soil type (five different types) and ground loop clearance from the foundation wall (four different clearances). The manipulated and fixed variables amounted to twenty different cases. The dependent variable in the simulation is the building heat loss.

The transient simulation function of HEAT3 had one major limitation. Unlike the surface temperature boundary condition which uses a TMY2 file as a time step function to vary temperature over time, the ground loop heat flux could not be input as a time step function, preventing automated daily variation. Instead, the ground loop heat flux had to be manually input every time there was a change in heat flux. Manually changing the heat flux daily over a 5-year simulation period for twenty cases would result in 36,500 input changes. To reduce the number of changes, it was decided that the ground loop heat flux would be changed on a weekly basis instead. This reduced the total number of simulation input changes down to 5,200. To determine the weekly ground loop heat flux, the average weekly outdoor air temperature in Duluth was matched with the corresponding expected ground heat fluxes previously presented in Table 7 of Section 3.2.3. The average outdoor temperature and weekly expected ground heat fluxes for all 52 weeks of the year in Duluth are presented in Table 13.

Table 13: Weekly ground loop heat flux

Week No.	Average Temperature [°C]	Ground Loop Heat Flux [W]
1	-10.0	-1141
2	-15.6	-1488
3	-5.3	-900
4	-18.1	-1613
5	-22.6	-1864
6	-14.5	-1425
7	-11.9	-1237
8	-1.9	-755
9	-9.0	-1093
10	-11.8	-1237
11	-1.2	-707
12	-2.2	-755
13	-1.7	-755
14	1.8	-563
15	3.6	-466
16	2.9	-514
17	3.1	-514
18	6.2	-370
19	8.8	-225
20	7.2	-322
21	11.5	-81
22	12.7	-32
23	14.0	16
24	17.2	160
25	13.4	-32
26	18.2	209
27	21.6	401
28	20.3	305
29	17.6	209
30	15.6	112
31	17.9	209
32	18.2	209
33	19.2	257
34	15.5	112
35	12.1	-81
36	16.1	112
37	12.0	-81
38	7.9	-273
39	8.8	-225
40	8.9	-225
41	7.4	-322
42	4.7	-418
43	4.6	-418
44	3.7	-466
45	3.9	-466
46	-1.5	-755
47	-9.2	-1093
48	-6.1	-948
49	-7.6	-1045
50	-13.5	-1368
51	-13.2	-1311
52	-11.4	-1198

The simulation on a per case basis was performed as such:

1) A 15-year simulation with no ground loop was first performed to reach steady state soil temperatures in the model.
2) The ground loop was placed in the model at the specified ground loop clearance and depth.
3) The week 1 ground loop heat flux was then input (i.e. -1141 W).
4) The simulation time period was set as day 0 to day 7 (i.e. week 1).
5) The simulation was run with the results automatically being recorded.

6) Steps 3 to 5 were repeated for the next week (i.e. week 2 with a ground loop heat flux of -1488 W and time period of day 7 to day 14).

7) Step 6 was repeated until 3 simulation years were completed. If the percent change in results between year 2 and 3 were below 5%, the simulation was considered complete. If the percent change was above 5%, the simulation was continued until the year to year percent change in results was below 5%. The time to reach steady state for all cases varied between 3 to 5 years and depended mainly on the soil properties.

8) Steps 1 to 7 were completed for all twenty test cases. (i.e. case 1 is soil 1 with a ground loop clearance of 10cm and case 2 is soil 1 with a ground loop clearance of 50cm, etc). A listing of all simulation cases are presented in Table 14.

Table 14: Simulation cases

Case No.	Ground Loop Clearance [cm]	Soil Type	Case No.	Ground Loop Clearance [cm]	Soil Type
1	10	1	11	100	3
2	50	1	12	200	3
3	100	1	13	10	4
4	200	1	14	50	4
5	10	2	15	100	4
6	50	2	16	200	4
7	100	2	17	10	5
8	200	2	18	50	5
9	10	3	19	100	5
10	50	3	20	200	5

4 Results and Discussion

The heat transfer losses and gains for all five interior surfaces of the building were recorded for every simulation case. The source data can be found in Appendix 7.3. Due to the building’s rectangular shape, only 3 unique results are presented since sides 1 and 2 and sides 3 and 4 are identical. Figure 10 provides the identifiers for each interior surface.

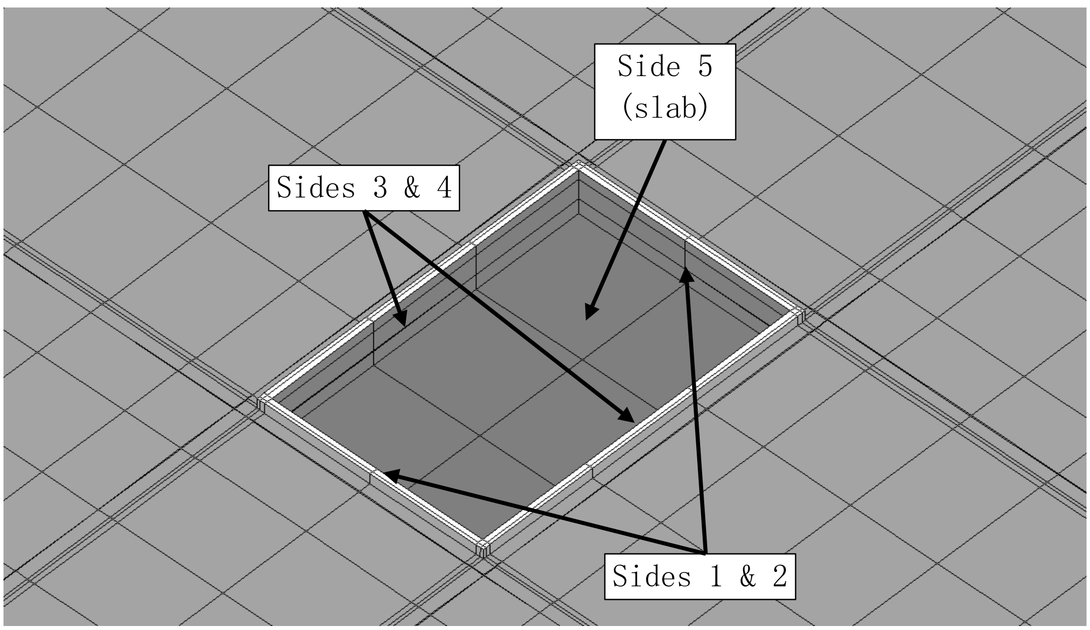


Figure 10: Interior surface identifiers

Figure 11 through Figure 30 represent the annual heat fluxes for sides 1&2 and 3&4, for soils 1 through 5, of the building for the following situations: no ground loop present, ground loop with 10cm clearance, ground loop with 50cm clearance, ground loop with 100cm clearance, and ground loop with 200cm clearance.

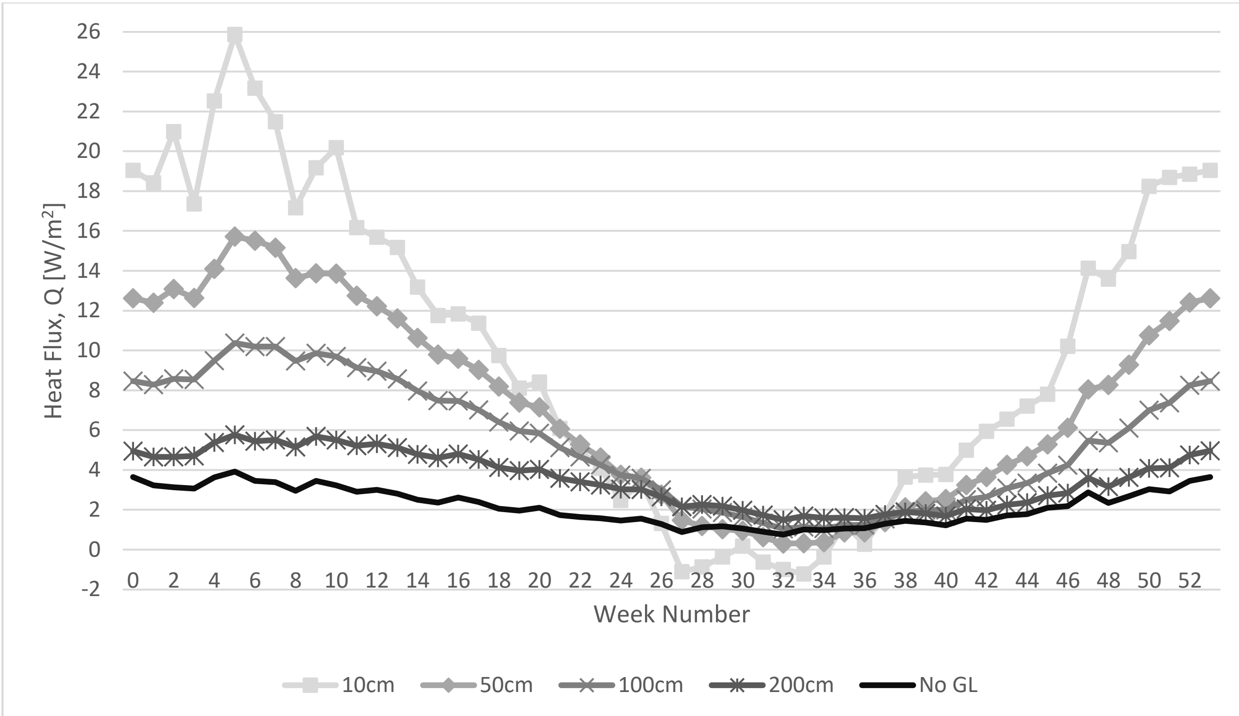


Figure 11: Annual heat flux of sides 1&2 – soil 1 (low λ, low VHC) [common scale]

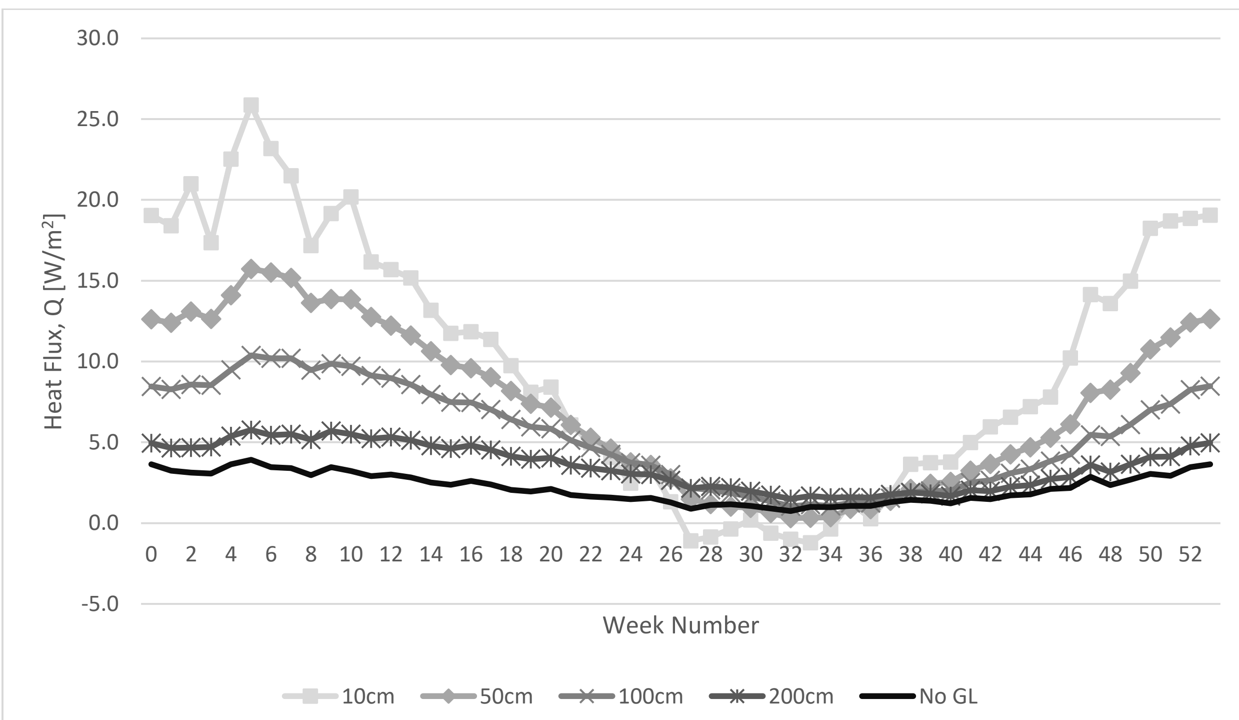


Figure 12: Annual heat flux of sides 1&2 – soil 1 (low λ, low VHC) [custom scale]

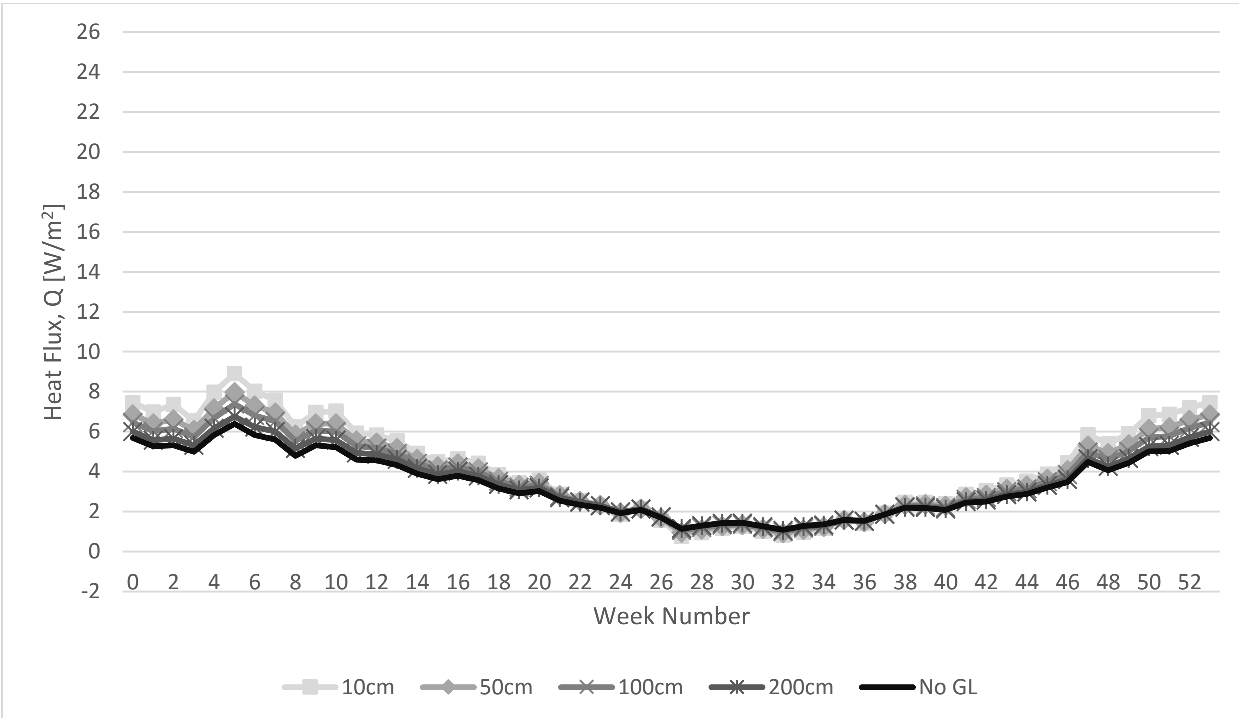


Figure 13: Annual heat flux of sides 1&2 – soil 2 (high λ, high VHC) [common scale]

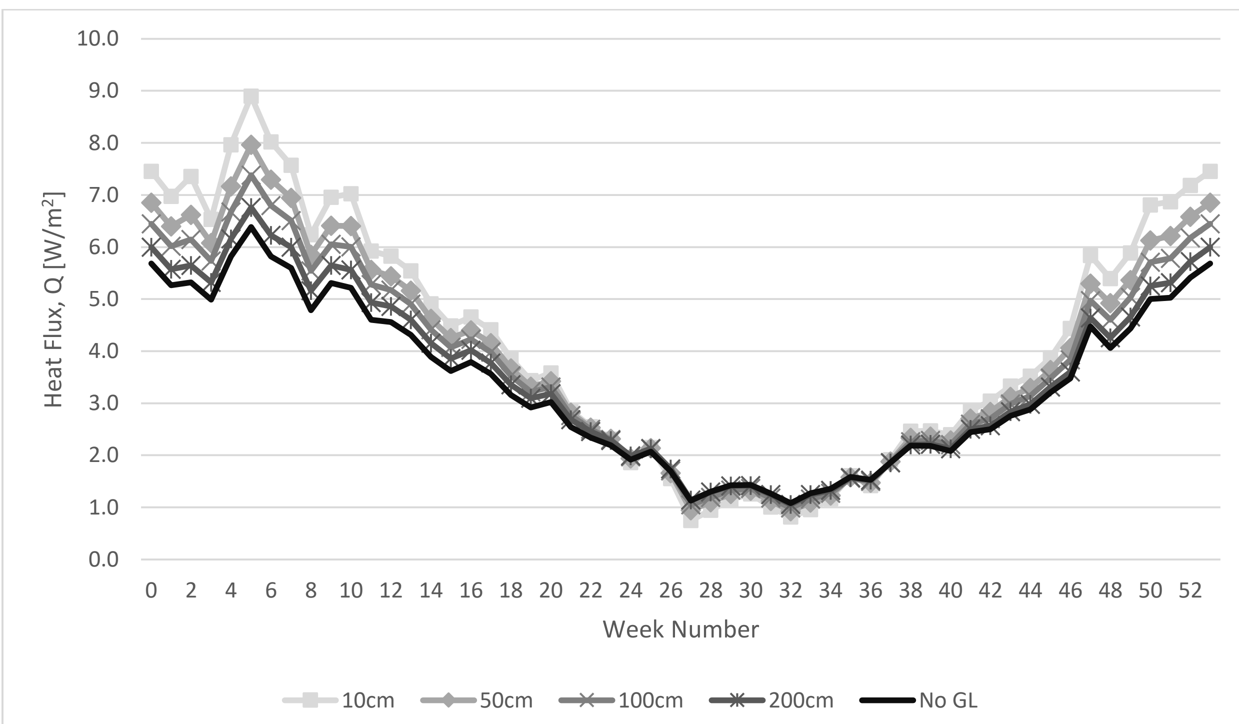


Figure 14: Annual heat flux of sides 1&2 – soil 2 (high λ, high VHC) [custom scale]

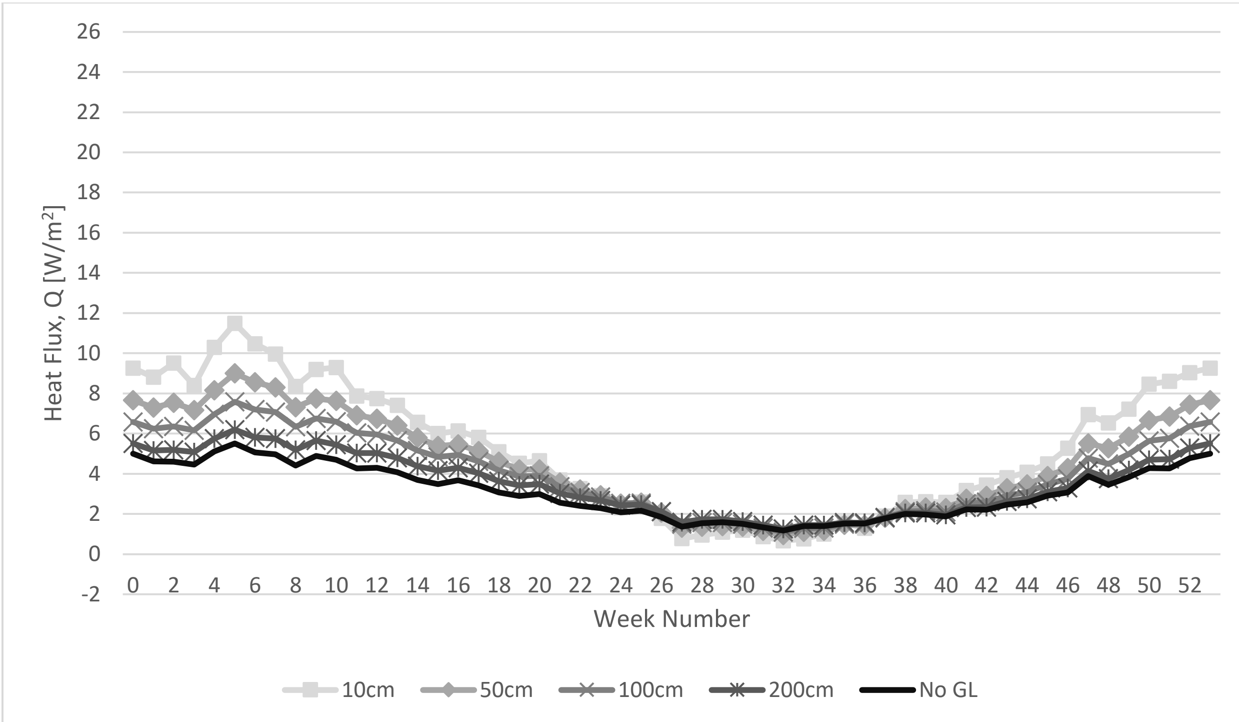


Figure 15: Annual heat flux of sides 1&2 - soil 3 (low λ, high VHC) [common scale]

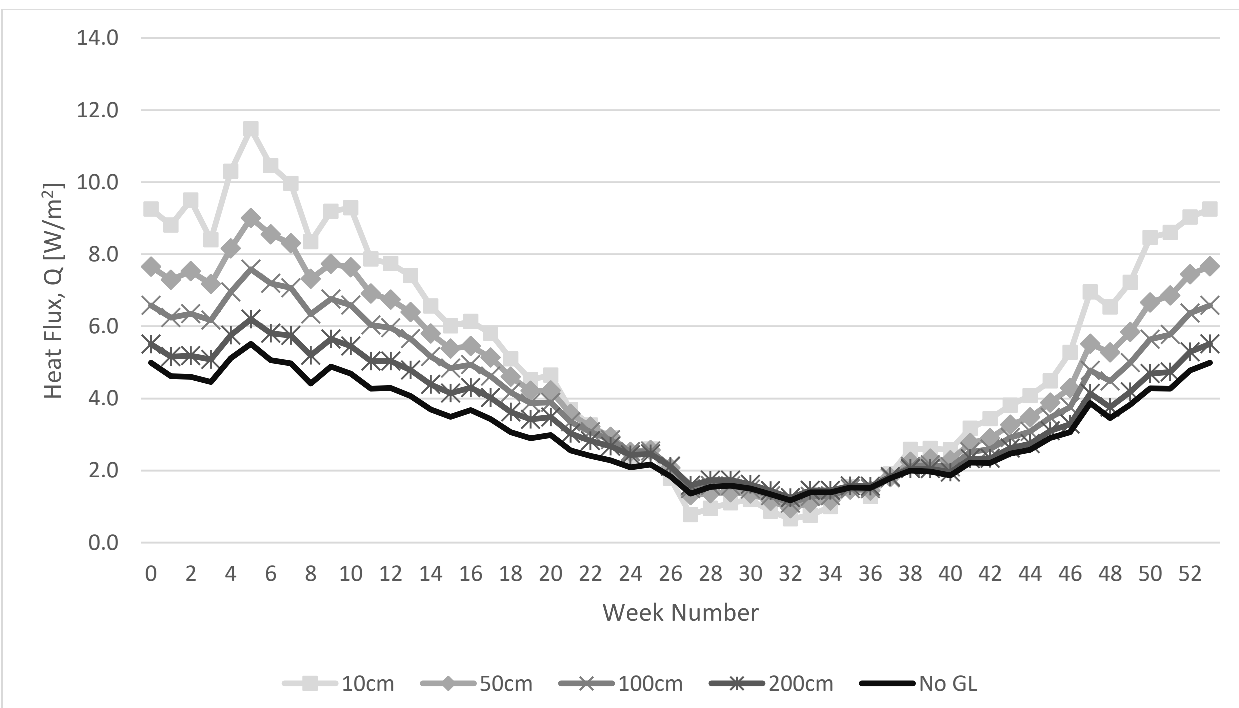


Figure 16: Annual heat flux of sides 1&2 - soil 3 (low λ, high VHC) [custom scale]

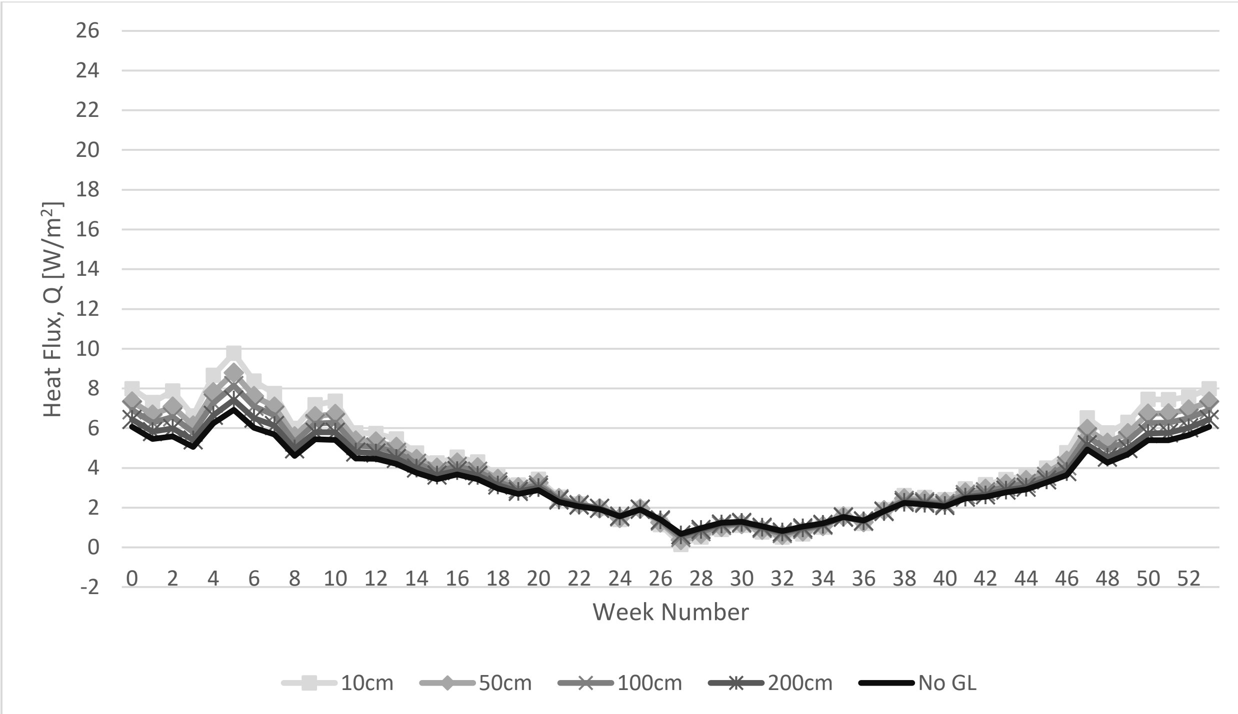


Figure 17: Annual heat flux of sides 1&2 - soil 4 (high λ, low VHC) [common scale]

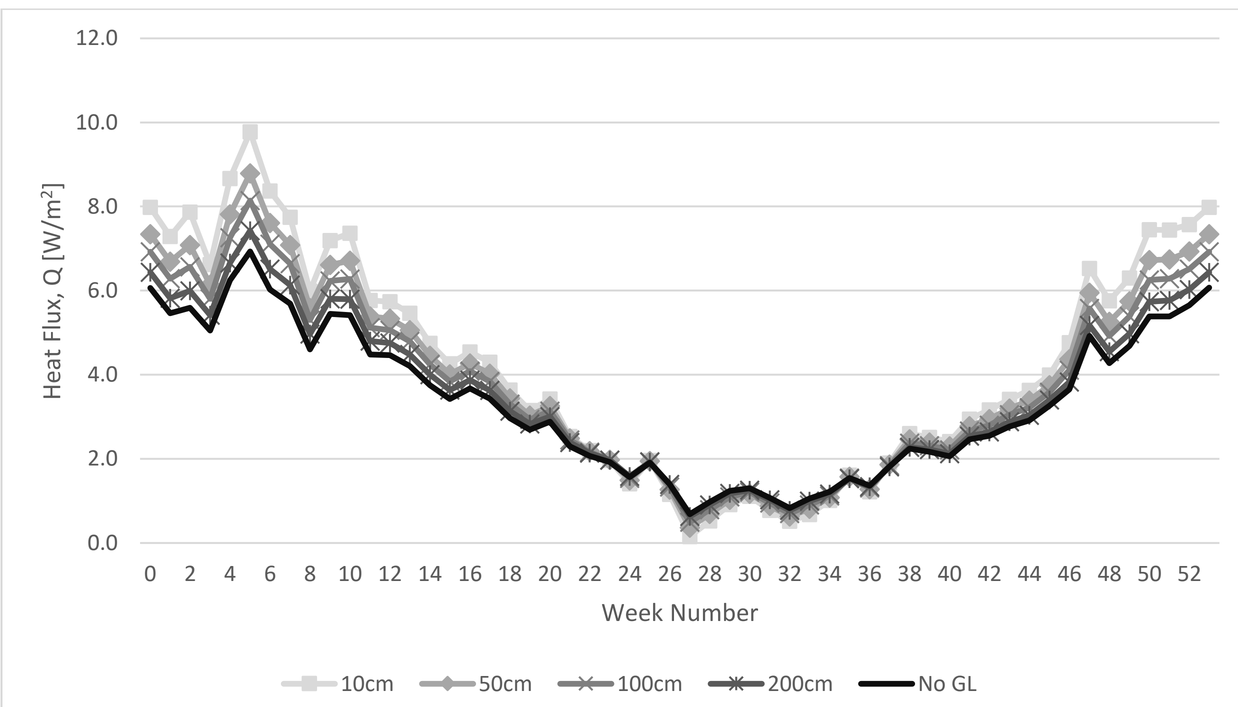


Figure 18: Annual heat flux of sides 1&2 - soil 4 (high λ, low VHC) [custom scale]

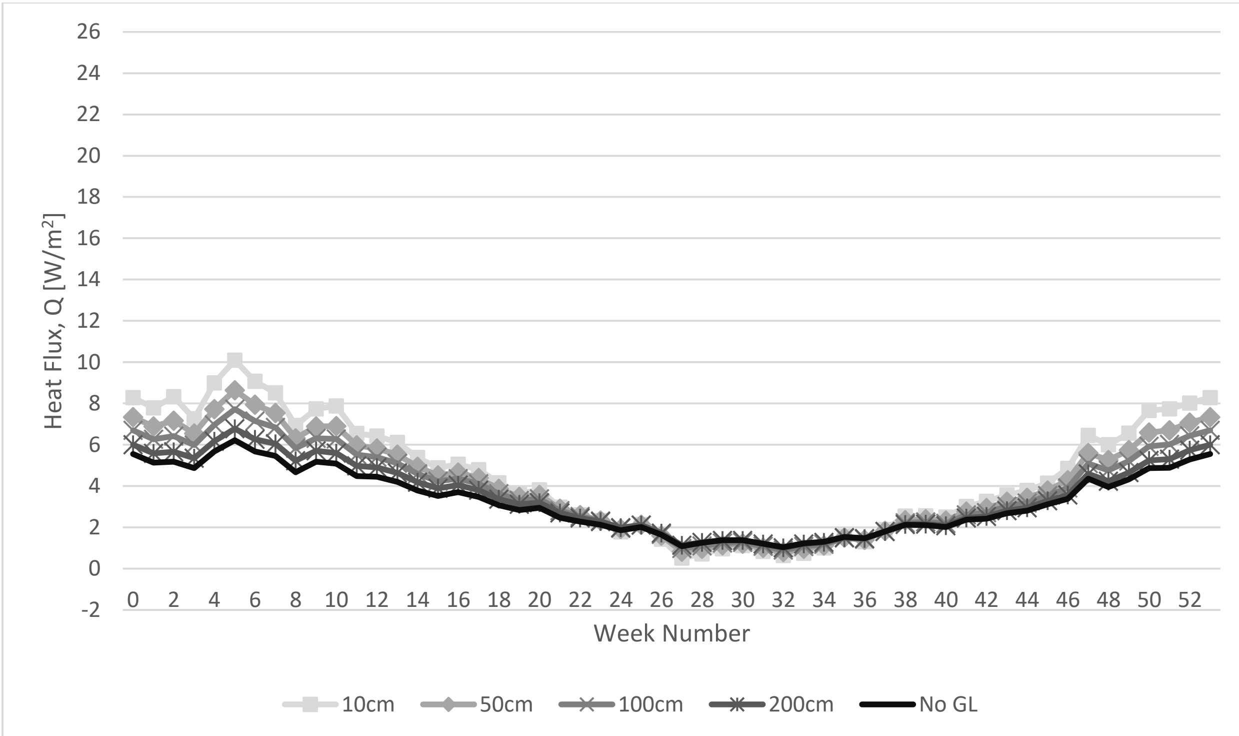


Figure 19: Annual heat flux of sides 1&2 - soil 5 (avg λ, avg VHC) [common scale]

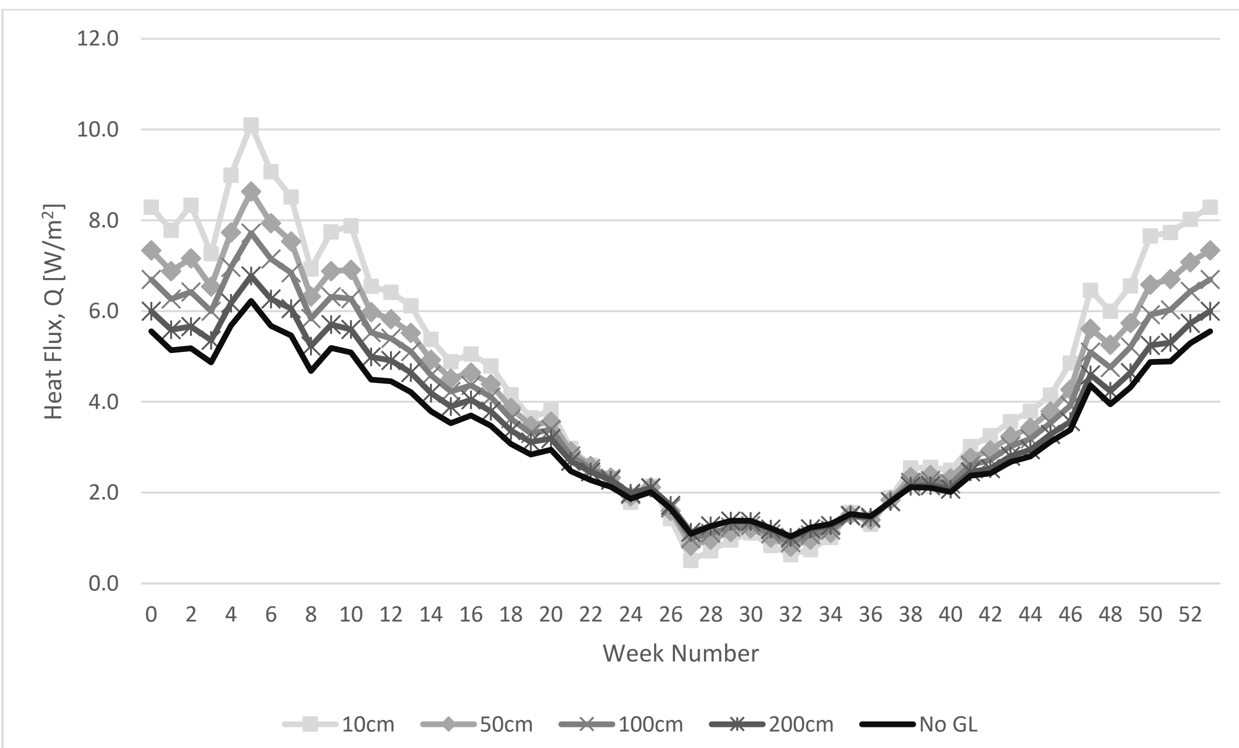


Figure 20: Annual heat flux of sides 1&2 - soil 5 (avg λ, avg VHC) [custom scale]

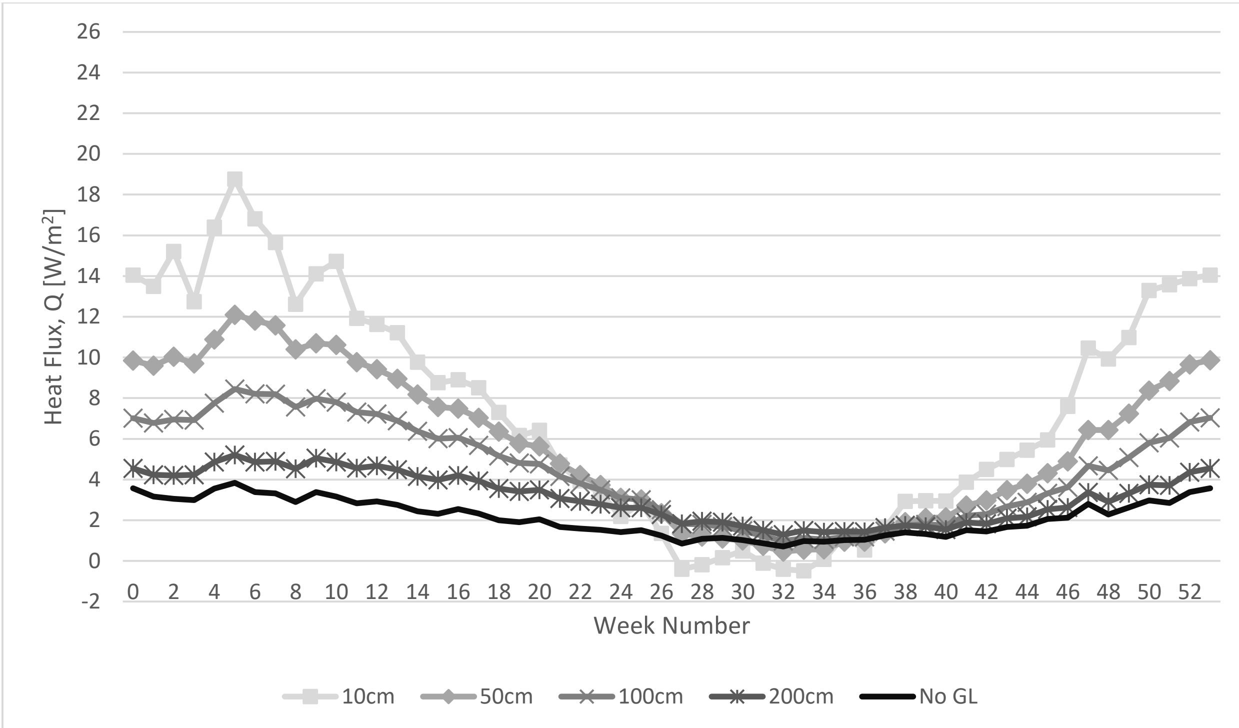


Figure 21: Annual heat flux of sides 3&4 - soil 1 (low λ, low VHC) [common scale]

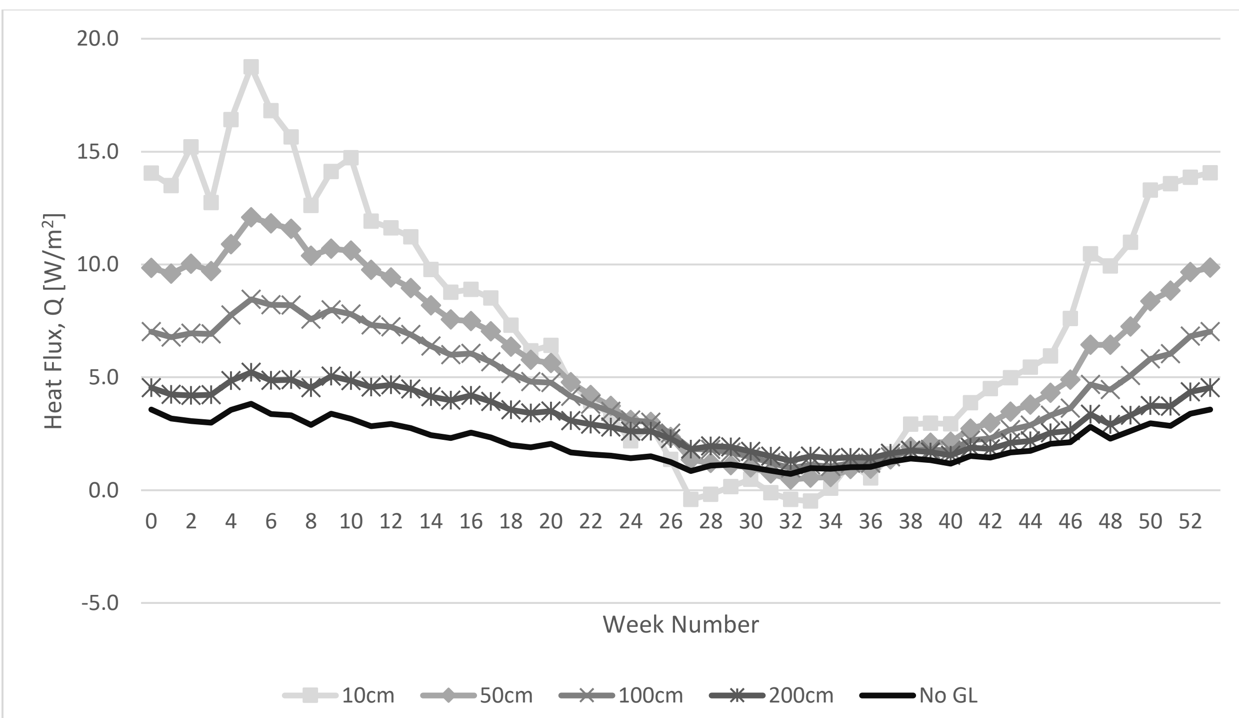


Figure 22: Annual heat flux of sides 3&4 - soil 1 (low λ, low VHC) [custom scale]

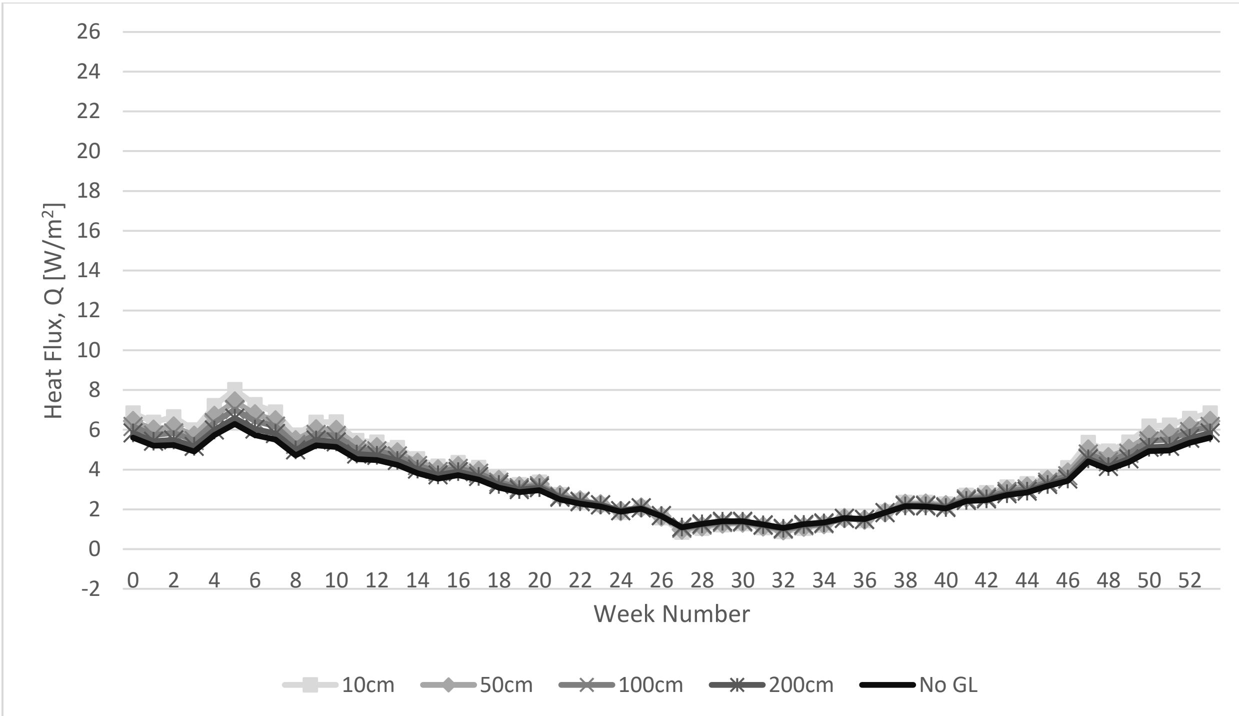


Figure 23: Annual heat flux of sides 3&4 - soil 2 (high λ, high VHC) [common scale]

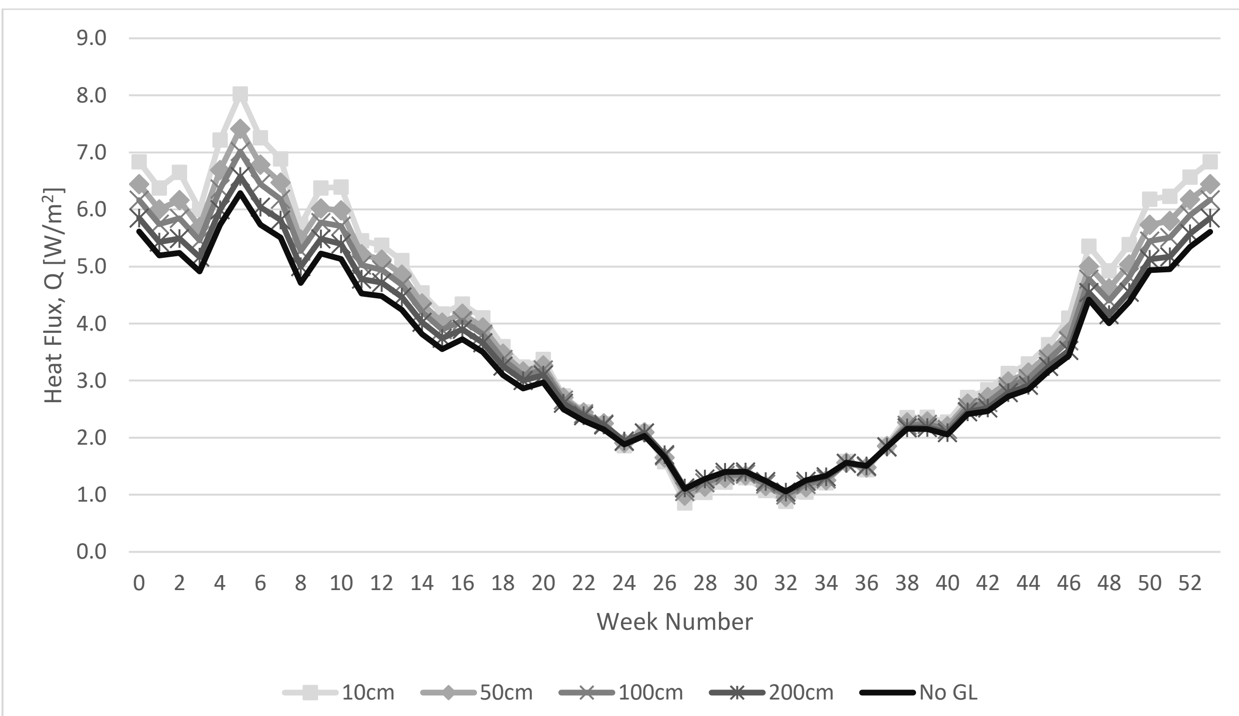


Figure 24: Annual heat flux of sides 3&4 - soil 2 (high λ, high VHC) [custom scale]

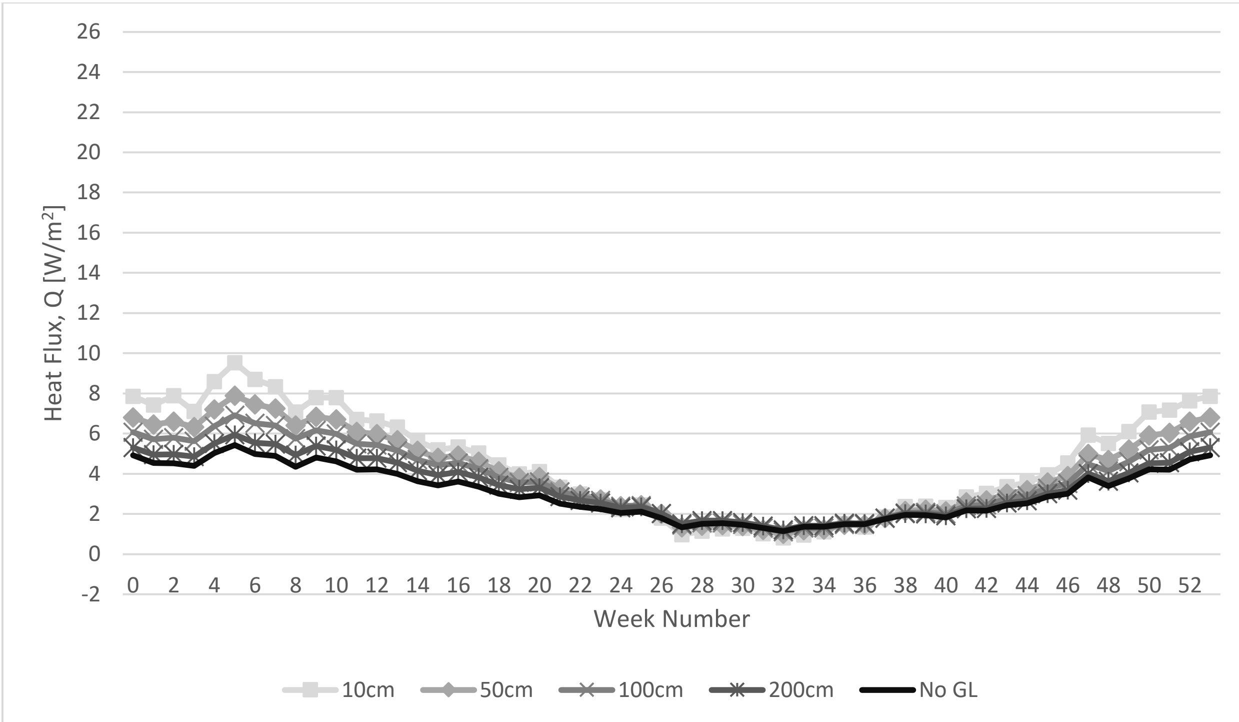


Figure 25: Annual heat flux of sides 3&4 - soil 3 (low λ, high VHC) [common scale]

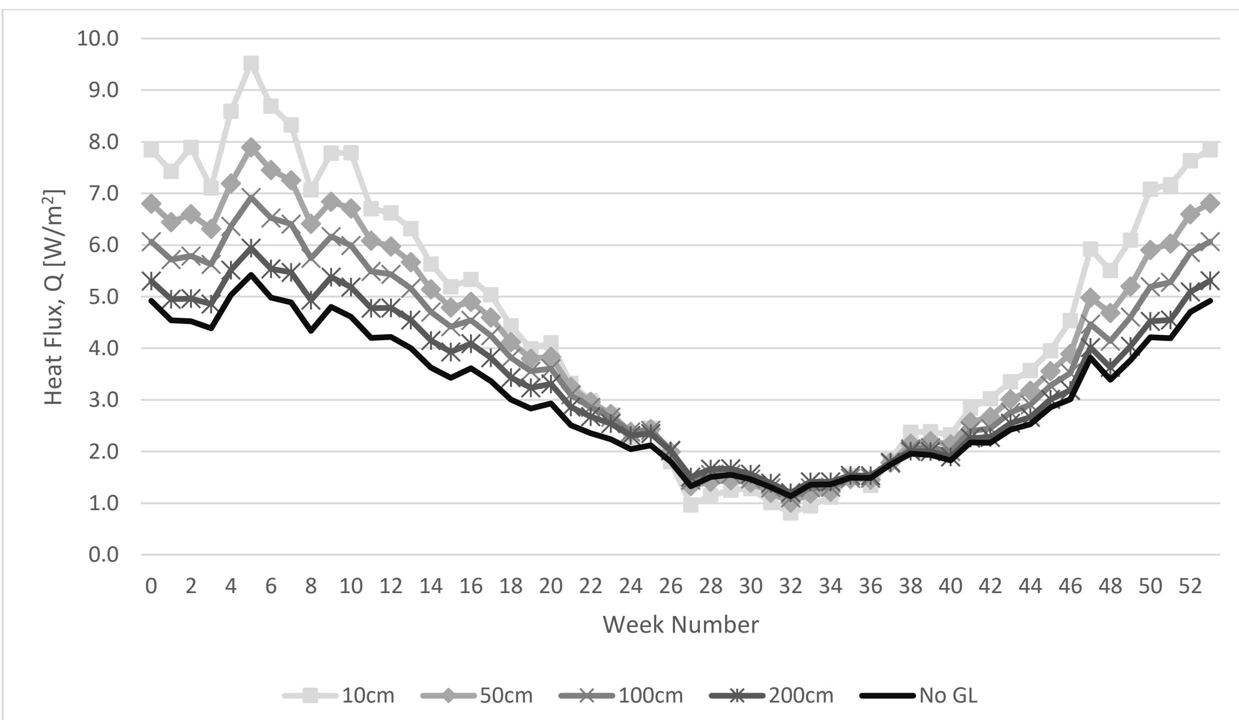


Figure 26: Annual heat flux of sides 3&4 - soil 3 (low λ, high VHC) [custom scale]

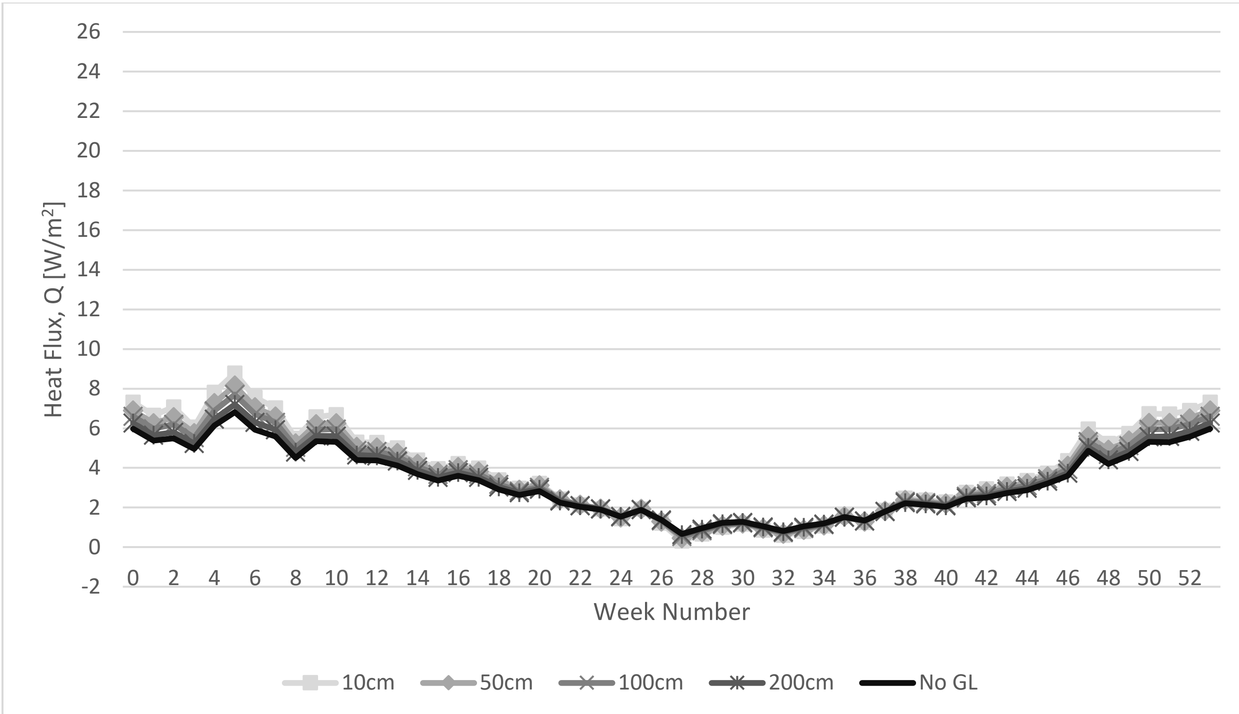


Figure 27: Annual heat flux of sides 3&4 - soil 4 (high λ, low VHC) [common scale]

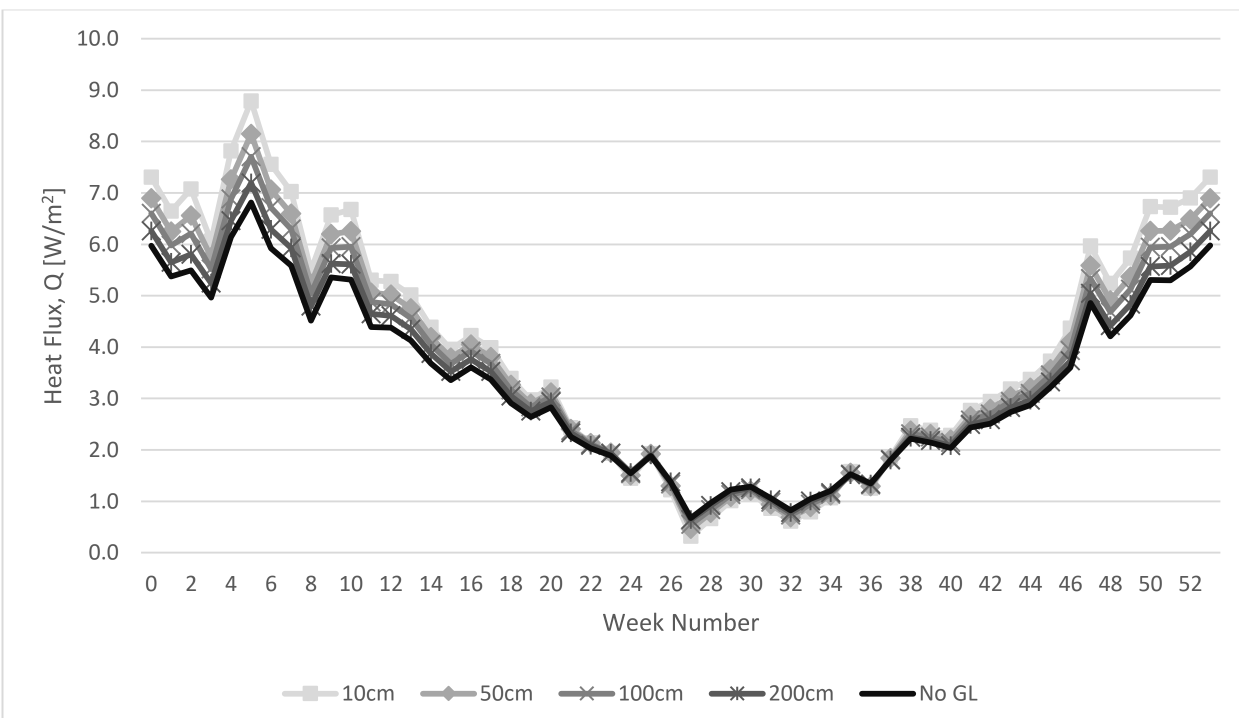


Figure 28: Annual heat flux of sides 3&4 - soil 4 (high λ, low VHC) [custom scale]

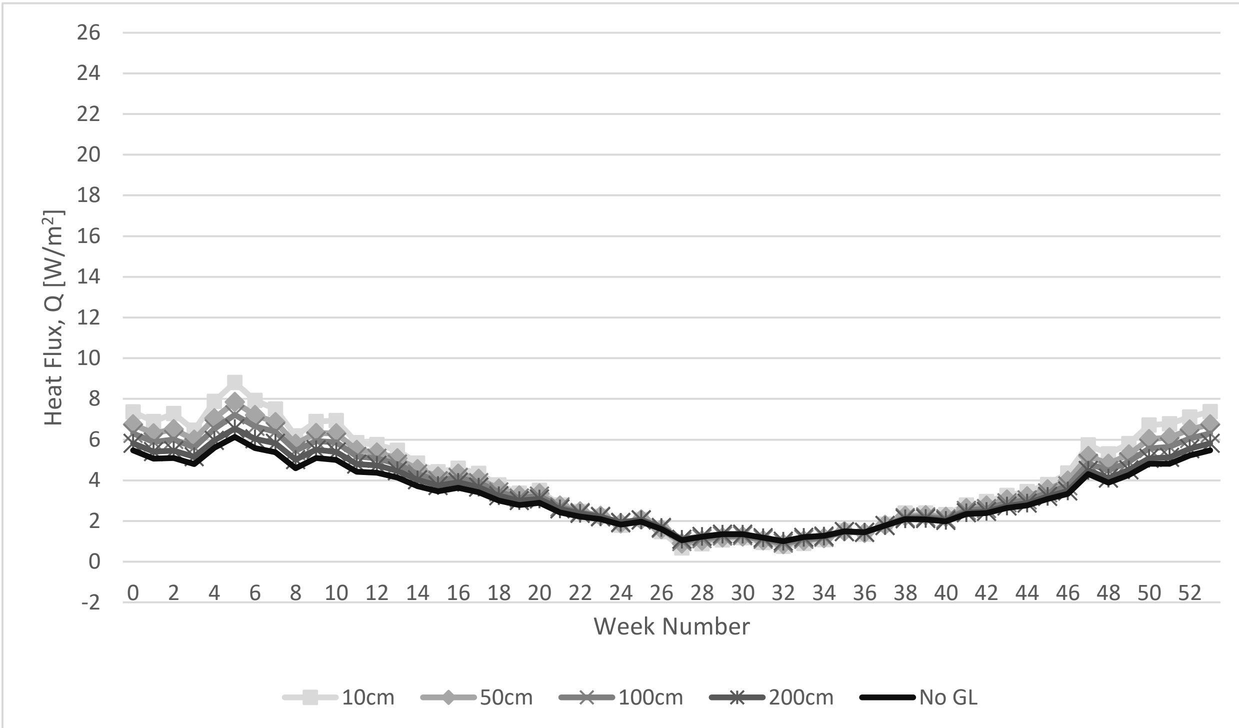


Figure 29: Annual heat flux of sides 3&4 - soil 5 (average λ, average VHC) [common scale]

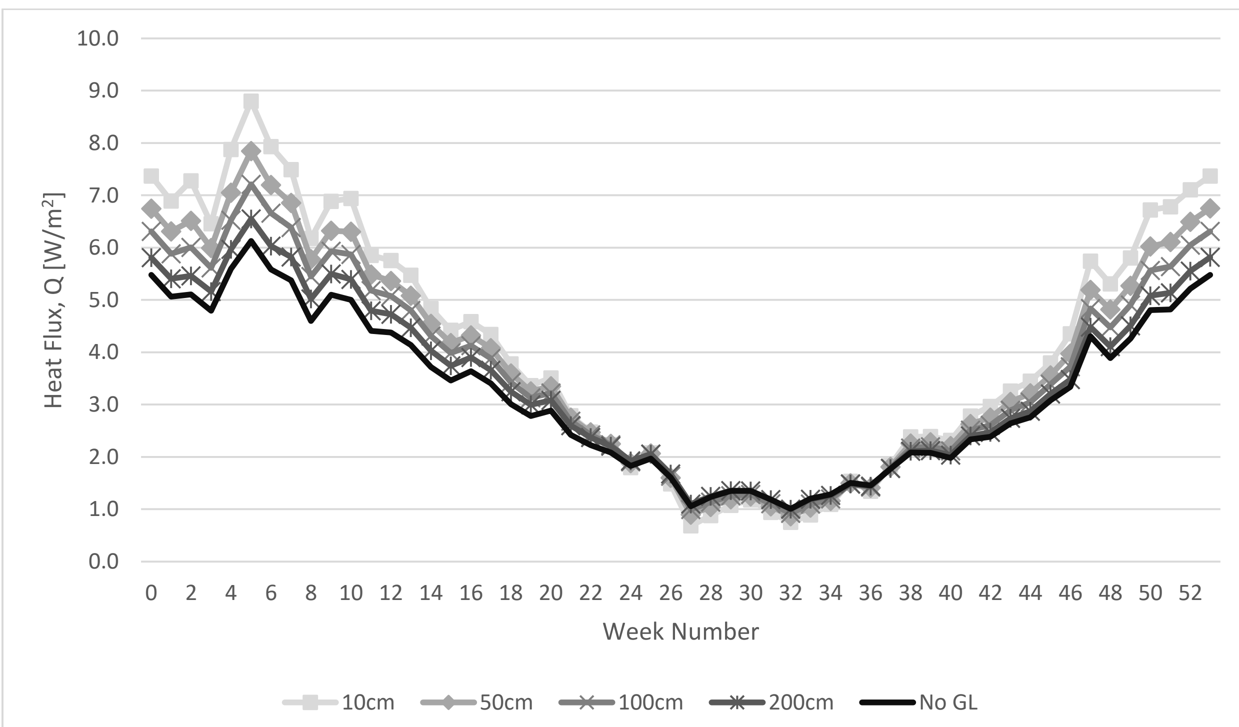


Figure 30: Annual heat flux of sides 3&4 - soil 5 (average λ, average VHC) [custom scale]

Several observations from the results presented in Figure 11 to Figure 30 can be made. First, the thermal conductivity of the soil impacts the effect that the ground loop clearance has on the building's heat loss. The soils with a higher thermal conductivity have narrower gaps in heat flux between the various ground loop clearances (i.e. trend lines are compressed closer). Arranging soils 1 to 5 from highest to lowest thermal conductivity results in the following order: soil 2, soil 4, soil 5, soil 3, then soil 1. This is the same order in terms of narrowest heat flux gap between ground loop clearances to largest heat flux gap (i.e. low effect to high effect of ground loop clearance), indicating a correlation between thermal conductivity and the ground loop clearance's impact on heat flux. A high thermal conductivity soil will reduce the effect that the ground loop clearance has on the building's heat loss. The opposite is true for a soil with low thermal conductivity.

As shown in Table 15 and Table 16, for a ground loop clearance of 10cm, the building's highest average heat loss of 10.0 W/m^2 for sides 1&2 and 7.5 W/m^2 for sides 3&4 occurs with soil 1, which has the lowest thermal conductivity. Conversely, the building's lowest average heat loss of 4.2 W/m^2 for sides 1&2 and 3.9 W/m^2 for sides 3&4 occurs with soil 2, which has the highest thermal conductivity. At a ground loop clearance of 10cm, the building's heat loss is shown to have a direct correlation with thermal conductivity. Although this result may seem counterintuitive, the reason for this correlation could be due to the close-proximity ground loop reducing the temperature of the soil directly adjacent to the foundation wall. The insulative surrounding soil (i.e. low thermal conductivity) inhibits the adjacent soil's ability to be recharged by the outdoor air and stable temperature soil below. This results in the adjacent soil temperatures remaining low, which has the overall effect of increased building heat losses. See Figure 31 for a schematic representation. Conversely, it can be viewed that the soil with high thermal conductivity allows heat escaping the building to more freely travel in various directions, thus less of it reaching the ground loop.

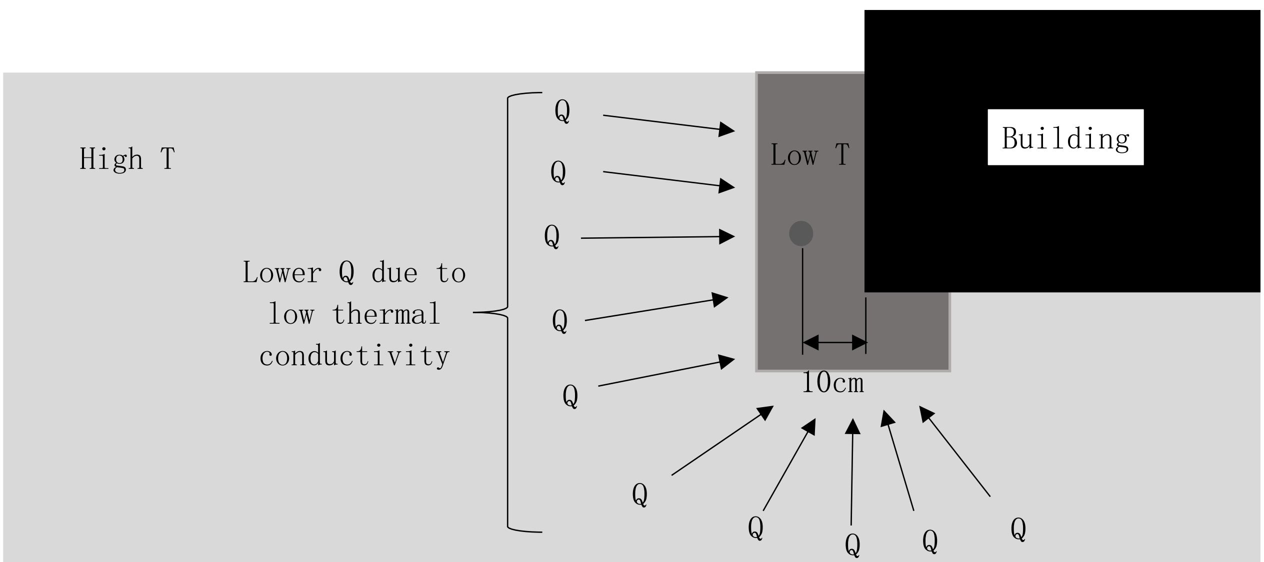


Figure 31: Schematic of the effect of an insulative soil

For 10cm clearance cases with high thermal conductivity soils, the soil temperature adjacent to the building can recharge quicker, leading to overall higher soil temperatures at the foundation wall and reduced building heat loss.

Table 15: Average building heat loss for four ground loop clearances on sides 1&2

Thermal Conductivity, k [W/(m·K)]	Average Heat Loss [W/m²]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
0.25 [Soil 1]	10.0	7.3	5.4	3.5
1.52 [Soil 3]	5.2	4.5	4.0	3.5
2.73 [Soil 5]	4.6	4.2	3.9	3.6
4.20 [Soil 4]	4.3	4.0	3.8	3.6
4.44 [Soil 2]	4.2	3.9	3.8	3.6

Table 16: Average building heat loss for four ground loop clearances on sides 3&4

Thermal Conductivity, k [W/(m·K)]	Average Heat Loss [W/m²]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
0.25 [Soil 1]	7.5	5.7	4.5	3.3
1.52 [Soil 3]	4.6	4.1	3.8	3.4
2.73 [Soil 5]	4.1	3.9	3.7	3.4
4.20 [Soil 4]	3.9	3.8	3.6	3.5
4.44 [Soil 2]	3.9	3.7	3.6	3.5

The average soil 1 building heat loss at clearances of 10cm, 50cm, and 100cm is greater than the average for soils 2 to 5. For sides 1&2, and all soils, the average building heat loss at a 10cm, 50cm, and 100cm clearance varies between 4.2 W/m^2-10.0 W/m^2, 3.9 W/m^2-7.3 W/m^2, and 3.8 W/m^2-5.4 W/m^2 respectively. This indicates that the soil type has an impact on the ground loop clearance's effectiveness on reducing building heat loss. However, for a clearance of 200cm, the average heat loss for soil 1 is essentially equal to the heat loss of soils 2 to 5. At a 200cm clearance, the average building heat loss for all soils varies between 3.5 W/m^2-3.6 W/m^2, which indicates that soil type has a limited impact on the ground loop clearance's effectiveness on reducing building heat loss when the ground loop clearance is 200cm. The same trends for sides 1&2 are observed for sides 3&4. Comparing soil 1 to soils 2 to 5, it is observed that the average building heat loss significantly drops as ground loop clearance is increased, indicating it is more beneficial for low thermal conductivity soils to have ground loops with greater clearances. In all cases, the building heat loss reduces with increasing ground loop clearance.

The second observation from Figure 11 to Figure 30, is that for all soil types, the trend line spacing between the 200cm ground loop clearance case and the no ground loop case is narrow, which indicates that the ground loop’s influence on the building’s heat loss is minimal when the ground loop is placed 200cm away. On average, the ground loop with a 200cm clearance increased the building’s heat losses by 15% on sides 1&2 and by 12% on sides 3&4. Conversely, a ground loop with a 10cm clearance, on average, increased the building’s heat losses by 83% on sides 1&2 and by 59% on sides 3&4. The average building heat loss increase for a 50cm clearance ground loop was 55% for sides 1&2 and 40% for sides 3&4. For a 100cm clearance ground loop, the average building heat loss was increased by 35% for sides 1&2 and 26% for sides 3&4. The heat loss percent increase, with no ground loop present as the baseline, for all four clearances and all five soil types for sides 1 through 4 are presented in Table 17 and Table 18.

Table 17: Building heat loss percent increase for four ground loop clearances on sides 1&2

Soil Number	Heat Loss Increase [%]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
1	356	233	147	61
2	24	16	11	5
3	67	45	29	12
4	26	17	12	5
5	38	26	17	8
Total Average	83	55	35	15

Table 18: Building heat loss percent increase for four ground loop clearances on sides 3&4

Soil Number	Heat Loss Increase [%]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
1	250	169	109	47
2	17	12	8	4
3	48	33	22	10
4	18	13	9	4
5	27	19	13	6
Total Average	59	40	26	12

It can be observed that the soils with a higher thermal conductivity (i.e. soils 2 and 4) have the lowest percent heat loss increase compared to the soils with lower thermal conductivities (i.e. soils 1, 3, and 5). This indicates that ground loop clearance is more critical for soils with lower thermal conductivity than for soils with higher thermal conductivity. In all soil cases, the percent heat loss increase decreases with increasing ground loop clearance.

The third observation from Figure 11 to Figure 30 is that for all soil cases, the summer time building heat flux is nearly identical for all ground loop clearances, as well as the no ground loop case. This is most likely due to the low ground loop heat fluxes during weeks 20 to 40 having less of an effect on the soil temperature than the outdoor air temperature. As previously noted, the low thermal conductivity soils (i.e. soil 1 and 3) produce trend line results with larger heat flux gaps between the ground loop clearances. For these soil types, the effect of increasing the ground loop clearance from 10cm to 50cm (40cm increase) on building heat flux is greater than the effect from increasing ground loop clearance from 50cm to 100cm (50cm increase). The ground loop clearance increase from 50cm to 100cm has a greater effect on building heat flux than the ground loop clearance increase from 100cm to 200cm (100cm increase). This indicates that initial ground loop clearance increases are the most important in terms of heat loss increase reduction. The soil cases with higher thermal conductivities (i.e. soil 2, soil 4, and soil 5) show that increasing the ground loop clearance from 10cm to 50cm, 50cm to 100cm, and 100cm to 200cm all reduce the heat flux by relatively the same amount on a percentage reduction basis.

Figure 32 to Figure 41 represent the heat loss of side 5, which is the building's slab. Soil 1's heat loss trendlines for the 10cm, 50cm, 100cm, and 200cm ground loop clearances show more variance from the no ground loop case compared to soils 2 to 5, however, the side 5 heat loss is the lowest for soil 1. Soil 1's no ground loop trendline is relatively flat throughout the year, indicating that the outdoor air temperature has negligible effect on the soil temperature under the slab due to the low thermal conductivity of the soil. For soils 2, 4, and 5, the trendlines between the 10cm, 50cm, 100cm, and 200cm ground loop clearances and the no ground loop case were relatively similar, differing by only 5% to 13%. For soil 3, the difference varied by 12% to 22%. The most significant increase in heat loss associated with the ground loop occurred for soil 1, with a heat loss increase varying between 68% to 109%. Table 19 provides the heat loss percent increase for side 5 of the building.

Table 19: Building heat loss percent increase for four ground loop clearances on side 5

Soil Number	Heat Loss Increase [%]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
1	106	109	96	68
2	8	8	7	5
3	22	21	17	12
4	9	8	7	5
5	13	12	10	7
Total Average	20	19	16	12

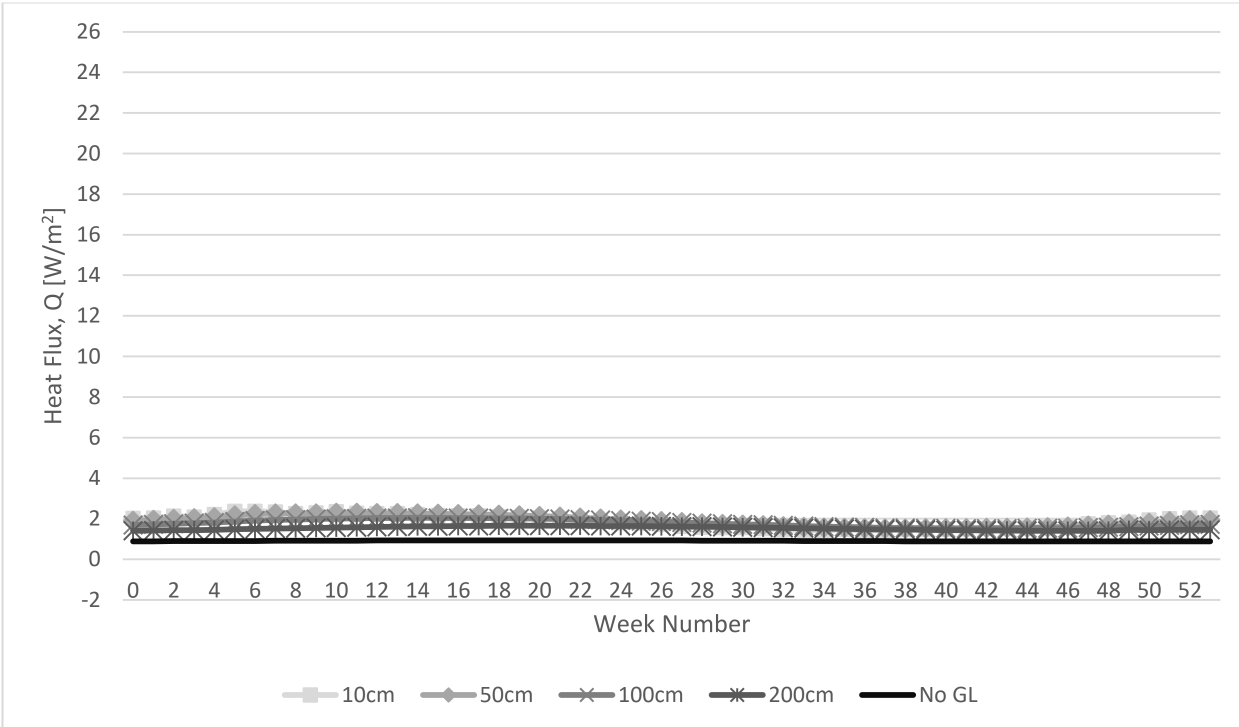


Figure 32: Annual heat flux of side 5 - soil 1 (low λ, low VHC) [common scale]

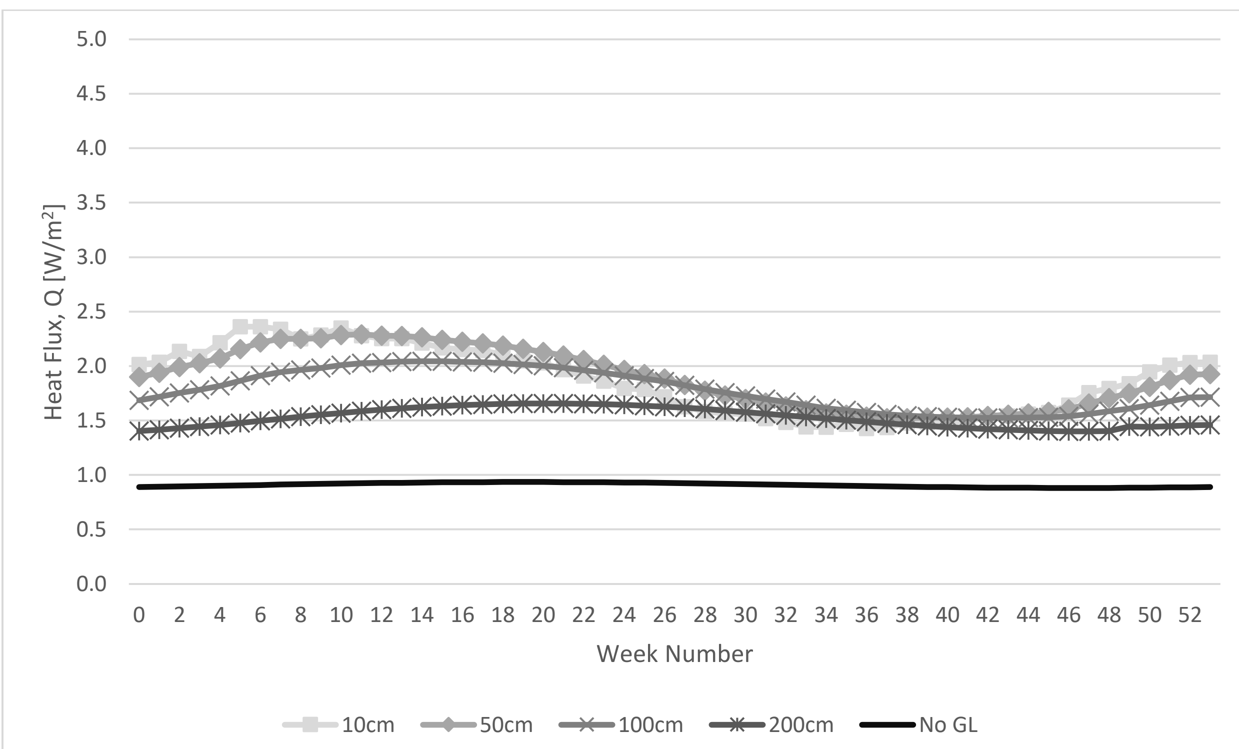


Figure 33: Annual heat flux of side 5 - soil 1 (low λ, low VHC) [custom scale]

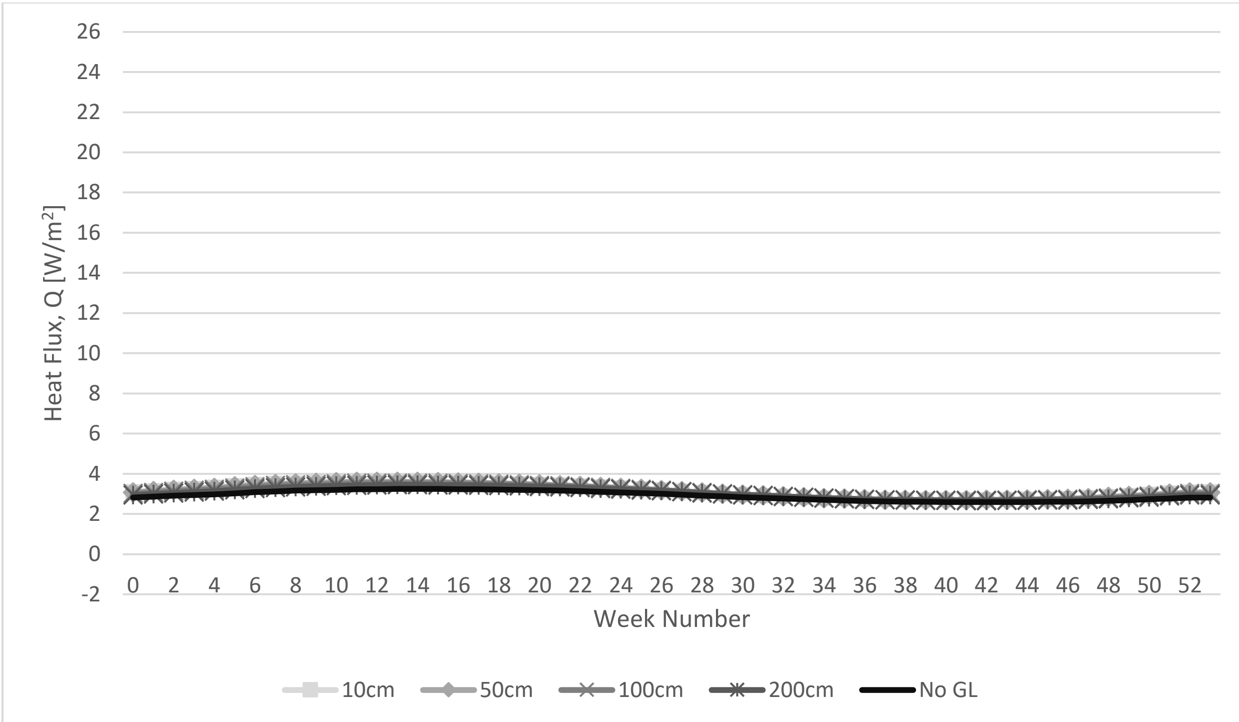


Figure 34: Annual heat flux of side 5 – soil 2 (high λ, high VHC) [common scale]

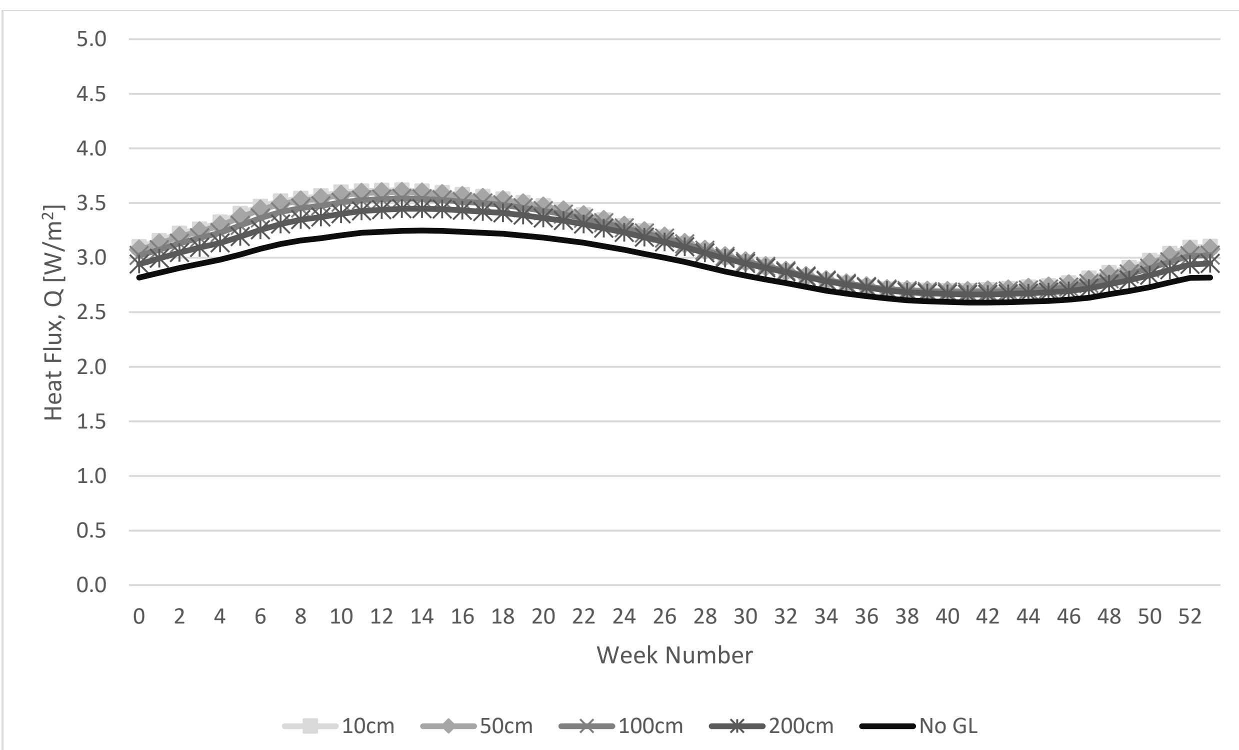


Figure 35: Annual heat flux of side 5 – soil 2 (high λ, high VHC) [custom scale]

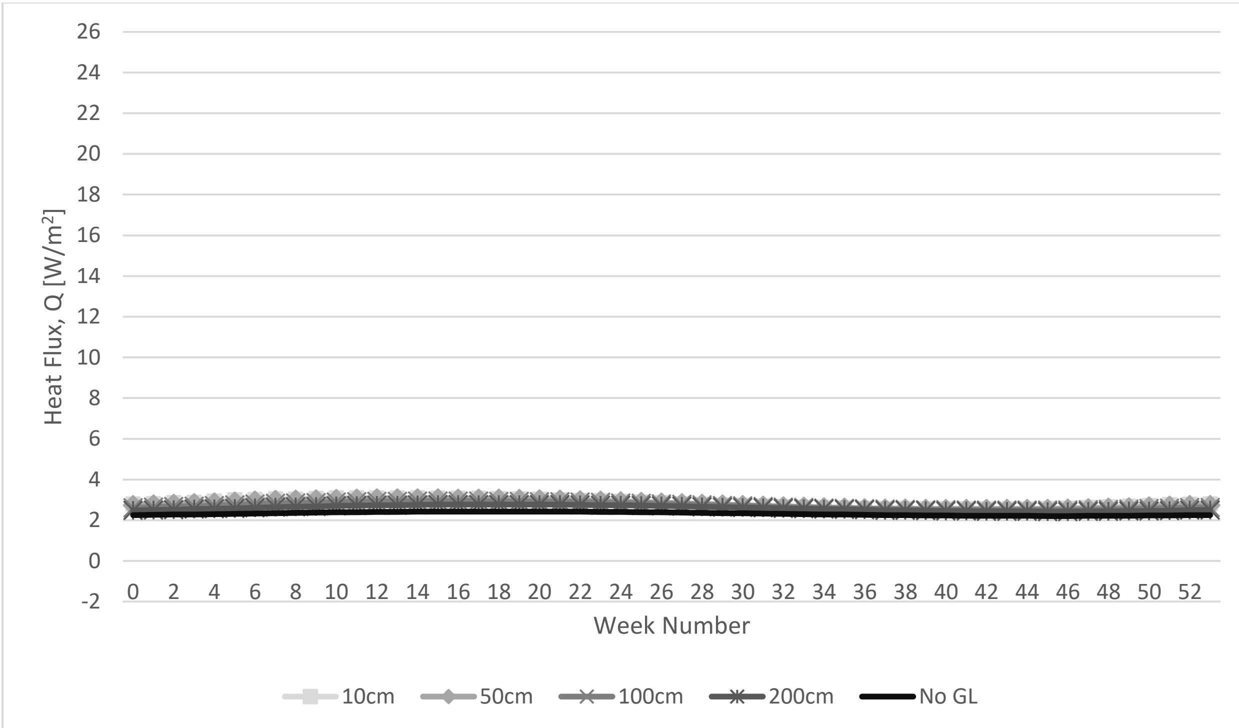


Figure 36: Annual heat flux of side 5 – soil 3 (low λ, high VHC) [common scale]

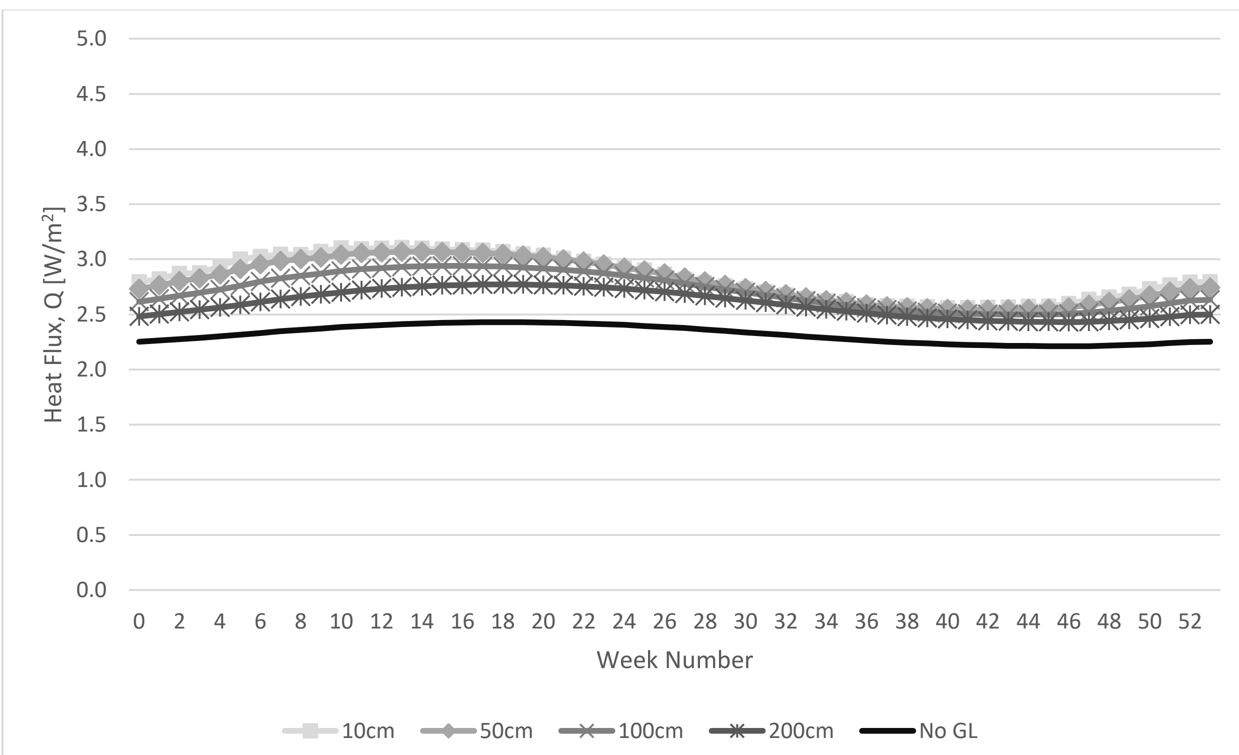


Figure 37: Annual heat flux of side 5 – soil 3 (low λ, high VHC) [custom scale]

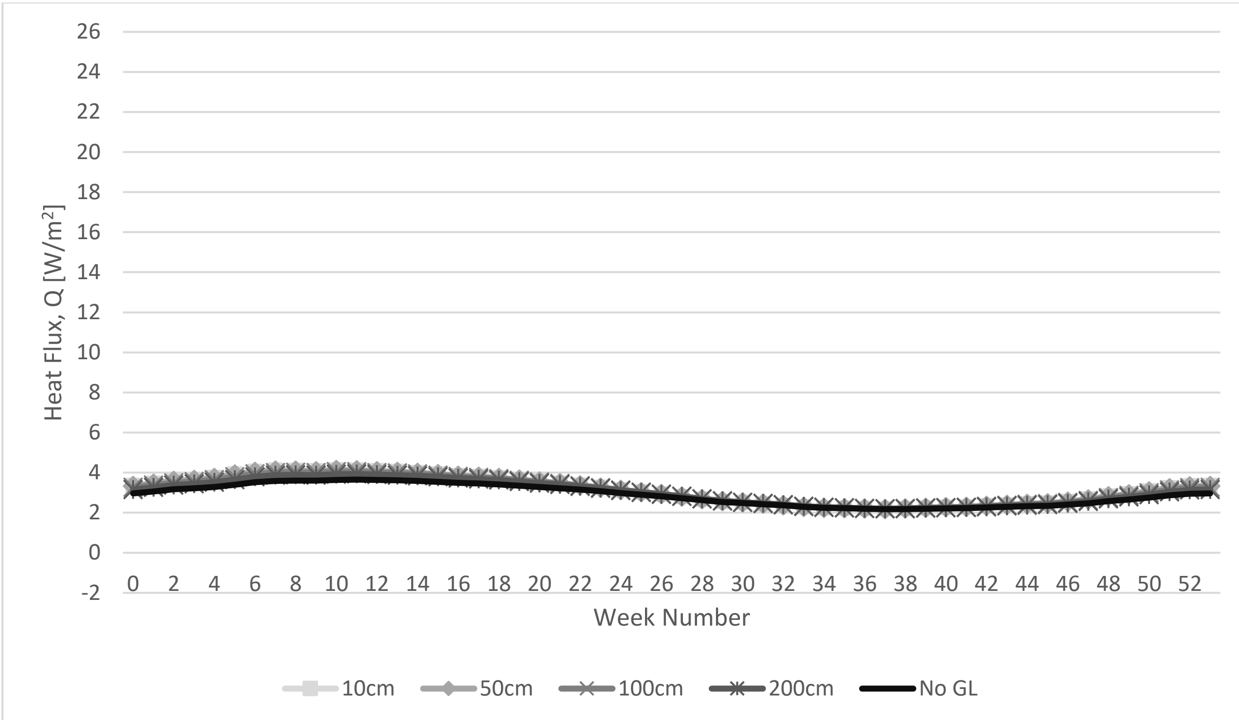


Figure 38: Annual heat flux of side 5 – soil 4 (high λ, low VHC) [common scale]

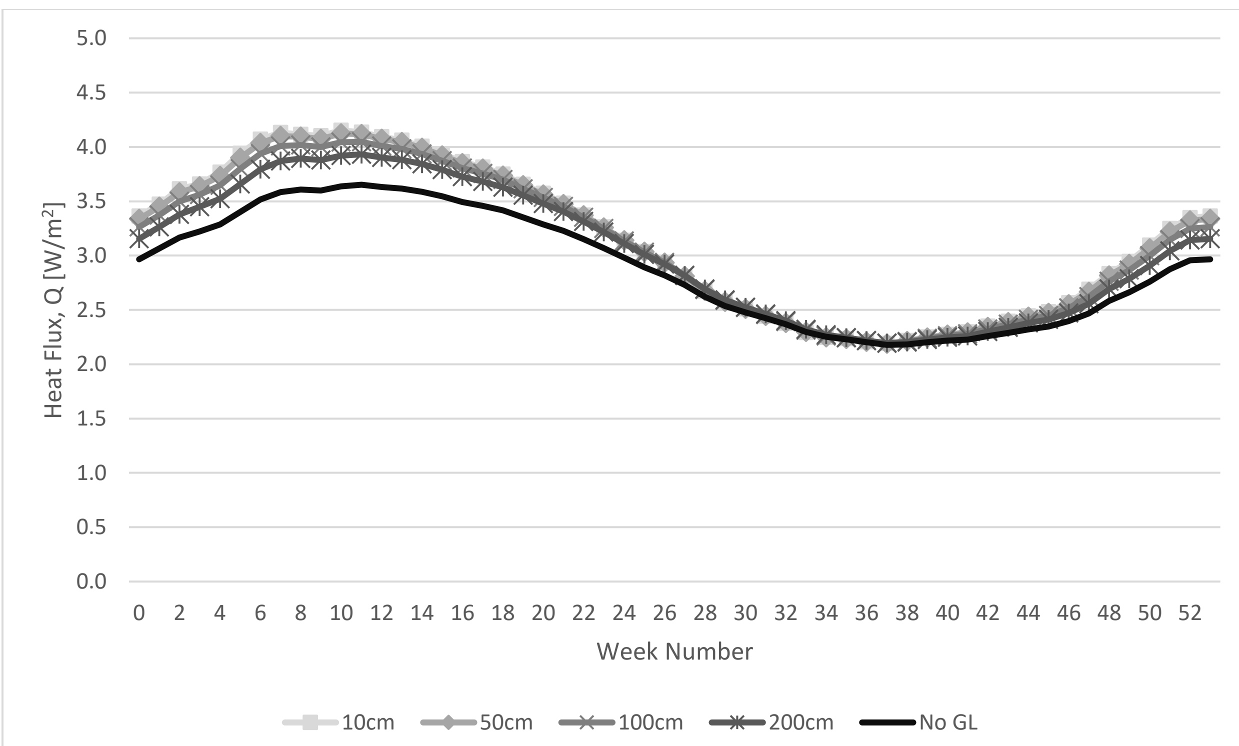


Figure 39: Annual heat flux of side 5 – soil 4 (high λ, low VHC) [custom scale]

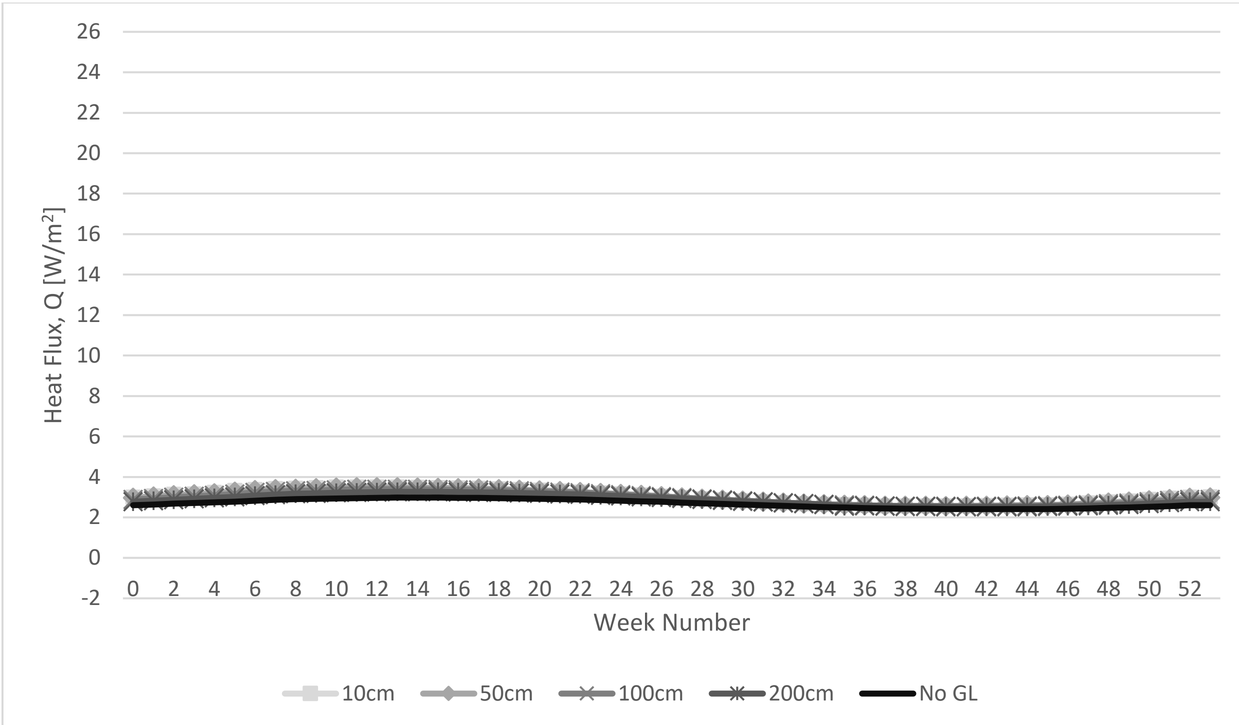


Figure 40: Annual heat flux of side 5 - soil 5 (average λ, average VHC) [common scale]

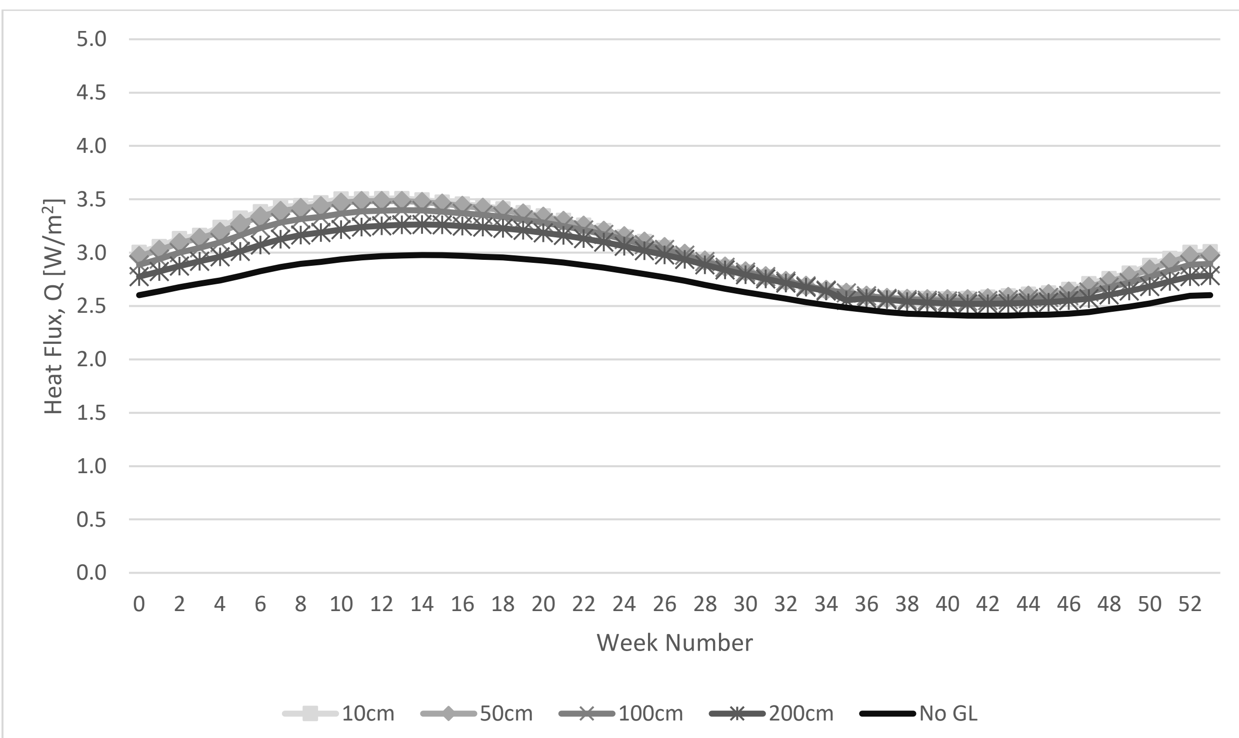


Figure 41: Annual heat flux of side 5 - soil 5 (average λ, average VHC) [custom scale]

Table 20 provides the average building heat losses of side 5 for soils 1 to 5. For soils 2 to 5, there is minimal variation in heat loss between a 10cm and 200cm ground loop clearance, with heat losses ranging from 2.8 – 3.1 W/m^2 to 2.6 – 3.0 W/m^2. The variation between a 10cm and 200cm ground loop clearance for soil 1 is 0.4 W/m^2, however, the average heat loss is lower than all other soils.

Table 20: Average building heat loss for four ground loop clearances on side 5

Thermal Conductivity, k [W/(m•K)]	Average Heat Loss [W/m^2]			
	Ground Loop Clearance			
	10cm	50cm	100cm	200cm
0.25 [Soil 1]	1.9	1.9	1.8	1.5
1.52 [Soil 3]	2.8	2.8	2.7	2.6
2.73 [Soil 5]	3.0	3.0	3.0	2.9
4.20 [Soil 4]	3.1	3.1	3.1	3.0
4.44 [Soil 2]	3.1	3.1	3.1	3.0

Figure 42 and Figure 43 represent the normalized heat loss of sides 1&2 and sides 3&4 respectively. The normalized results were produced by subtracting the baseline heat loss values of the no ground loop case from the heat loss values at ground loop clearances of 10cm, 50cm, 100cm, 200cm. Therefore, the results shown are the increase in building heat loss caused by the addition of a ground loop at the four clearances. The effect of increasing the ground loop clearance for the higher thermal conductivity soils (soils 2, 4, and 5) is minimal. Ground loop clearance has a minor impact for soil 3 (low thermal conductivity) and a very significant impact for soil 1 (lowest thermal conductivity).

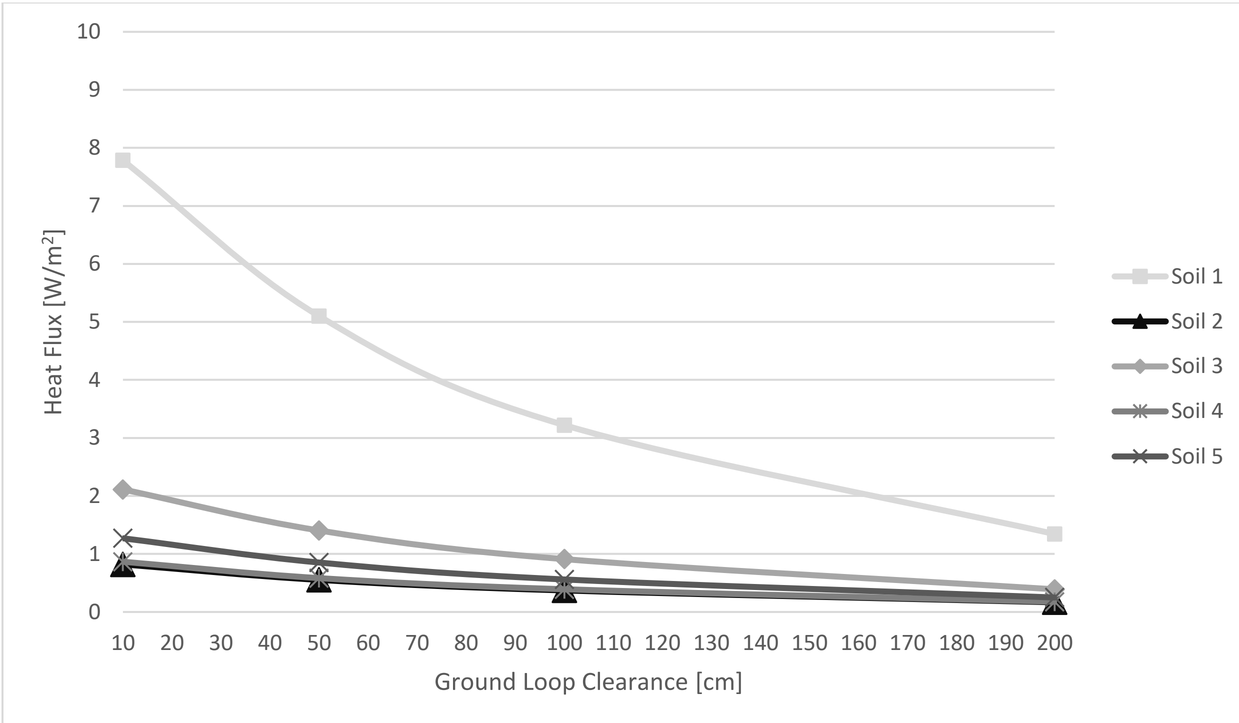


Figure 42: Normalized heat loss of sides 1&2 for all soil types

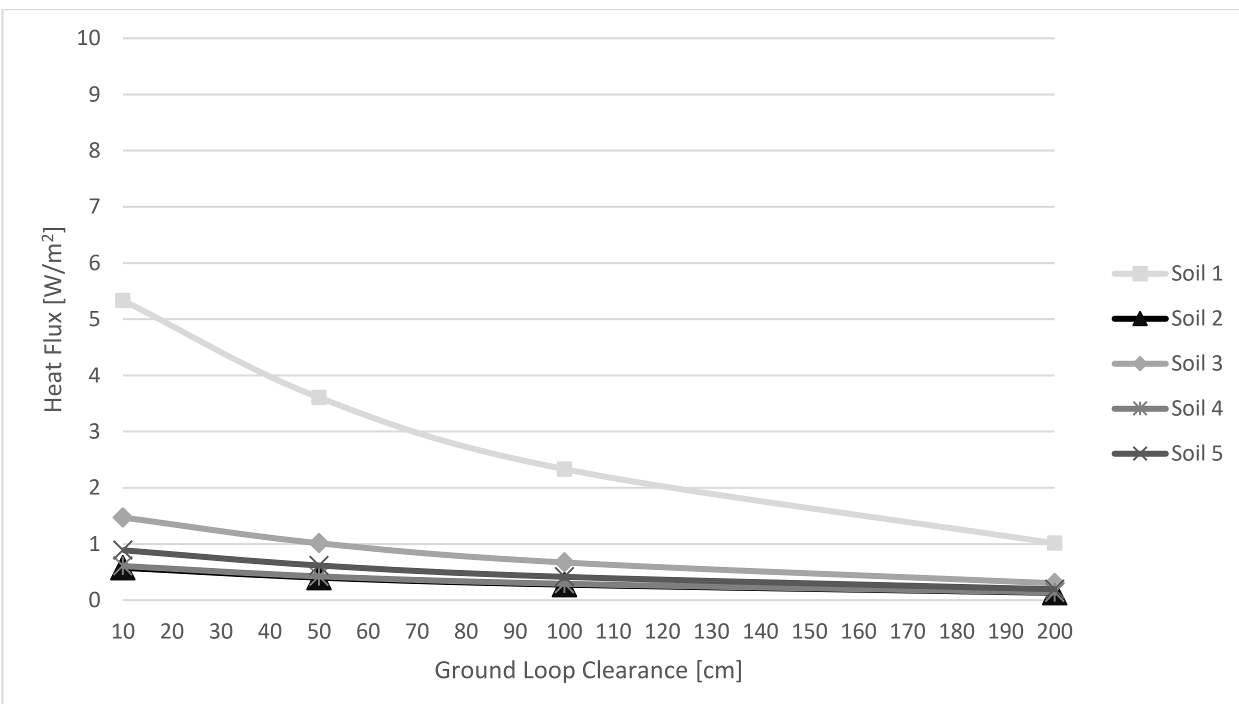


Figure 43: Normalized heat loss of sides 3&4 for all soil types

The side 5 trend lines shown in Figure 44 are flatter than those shown for sides 1&2 and 3&4. This indicates that the distance of the ground loop has a more limited effect on the heat loss of side 5 than on any other side. The flatness of the trend lines also shows that the ground loop’s influence on the soil temperature below side 5 is negligible.

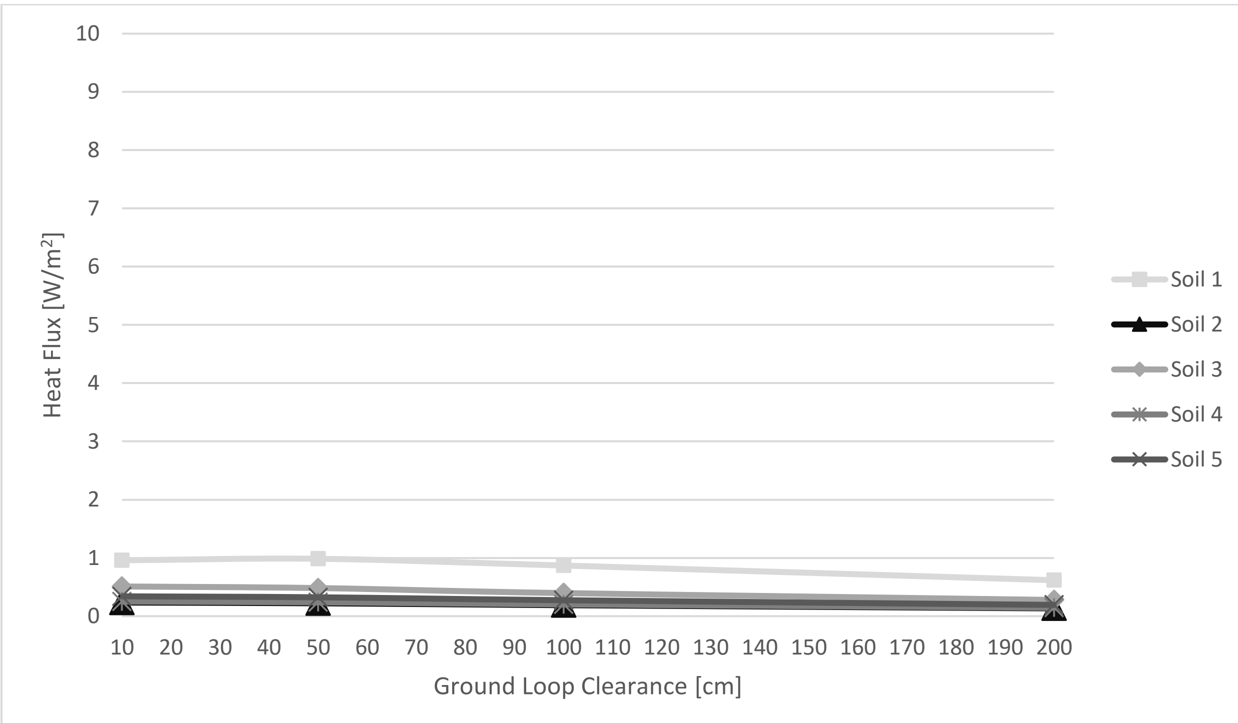


Figure 44: Normalized heat loss of side 5 for all soil types

5 Conclusions

Several conclusions can be drawn from the results presented in Section 4. The thermal conductivity of a building's surrounding soil has a large impact on the effect that ground loop clearance has on building heat loss. Soil thermal conductivity can range from a low of 0.15 W/m•K to a high of 5.0 W/m•K. For a low thermal conductivity soil, the building heat loss percent increase from a ground loop at a 10cm clearance versus a ground loop at a 200cm clearance decreases from 356% to 61%, which is a difference of 295%. For a medium thermal conductivity soil, the heat loss percent increase decreases from 67% to 12%, which is a difference of 55%. Lastly, for a high thermal conductivity soil, the heat loss percent increase decreases from 26% to 5%, which is a 21% decrease. These results show that increasing ground loop clearance is more effective in reducing increases in building heat loss for soils with low thermal conductivities than for soils with high thermal conductivities.

For all ranges of soil thermal conductivity, increasing ground loop clearance reduced the building percent heat loss increase associated with the operation of the ground loop. On average, the percent heat loss increase of the building decreased from 59%-83% (10cm clearance) to 40%-55% (50cm clearance) to 26%-35% (100cm clearance) to 12%-15% (200cm clearance). For ground loop clearances of 10cm, 50cm, and 100cm, the average building heat loss was shown to be directly correlated to the thermal conductivity of the surrounding soil. A low thermal conductivity soil led to higher observed building heat losses caused by the operation of the ground loop. For the case of no ground loop, the high thermal conductivity soils led to higher observed building heat losses. At a 200cm ground loop clearance, the average building heat loss of sides 1&2 and 3&4 was essentially the same for all soil types. This indicated that at a ground loop clearance of 200cm, the correlation between soil thermal conductivity and building heat loss decouples and that soil thermal properties become less influential on the building heat losses observed.

Low thermal conductivity soils were shown to have a greater benefit to reducing building heat loss by increasing ground loop clearance than did higher thermal conductivity soils. Soils 1 and 3 had average decreases in building heat losses from 7.5-10 W/m^2 to 3.1-3.5 W/m^2 and 4.6-5.2 W/m^2 to 3.4-3.5 W/m^2 respectively. Whereas soils 2, 4, and 5 had decreases in average building heat losses of 3.9-4.2 W/m^2 to 3.5-3.6 W/m^2, 3.9-4.3 W/m^2 to 3.5-3.6 W/m^2, and 4.1-4.6 W/m^2 to 3.4-3.6 W/m^2 respectively. Therefore, more emphasis should be placed on ensuring higher ground loop clearances for any installation locations with lower thermal conductivity soils.

On average, a ground loop with a 10cm clearance increased the building's heat losses by 83% on sides 1&2, by 59% on sides 3&4, and by 20% on side 5. A ground loop at 50cm clearance led to a building heat loss increase of 55% for sides 1&2, 40% for sides 3&4, and 19% on side 5. For a 100cm clearance, the average building heat loss increase was 35% for sides 1&2, 26% for sides 3&4, and 16% for side 5. Finally, for the 200cm ground loop clearance, the average increase in building heat loss for sides 1&2, sides 3&4, and side 5 was 15%, 12%, and 12% respectively. A building's overall heat loss increase resulting from a 200cm clearance ground loop would be minimal in a big picture scale once all other building envelope heat losses are considered.

Soils with a higher thermal conductivity (i.e. soils 2, 4, and 5) have the lowest percent heat loss increase compared to the soils with lower thermal conductivities (i.e. soils 1 and 3). In all soil cases, the percent heat loss increase decreases with increasing ground loop clearance. For low thermal conductivity soils, the effect of increasing the ground loop clearance from 10cm to 50cm (40cm increase) on building heat loss is greater than the effect from increasing ground loop clearance from 50cm to 100cm (50cm increase). The ground loop clearance increase from 50cm to 100cm has a greater effect on building heat loss than the ground loop clearance increase from 100cm to 200cm (100cm increase). This indicates that the initial increase in ground loop clearance is the most beneficial in terms of reducing the increase in building heat loss caused by the operation of the ground loop. The heat loss reduction effect of increasing the ground loop clearance for the high thermal conductivity soils (soils 2, 4, and 5) is minimal. Ground loop clearance has a minor impact for soil 3 (low thermal conductivity) and a very significant impact for soil 1 (lowest thermal conductivity).

5.1 Future Work

The overall goal of this research was to obtain preliminary findings to begin the process of developing a guideline for prescribing ground loop clearance from foundation walls. However, in order to develop a complete and robust guideline, additional work to expand on the preliminary findings will be necessary.

The majority of the recommended additional work will be an expansion of the current findings. This includes testing additional locations, soil types, and ground loop clearances. By testing locations in different climate zones, more robust data can be obtained for ground loop clearances since results will be obtained from both heating and cooling dominated climates. Although five soil types were tested, the variance in soil properties is so great that testing more types will help in obtaining stronger data, which can be used for further validation and confirmation of the observed trends. It is also recommended that further analysis into the effect that a soil's volumetric heat capacity has on building heat loss. This can be done by keeping the thermal conductivity of the test soils constant and varying the volumetric heat capacity. Furthermore, testing additional ground loop clearances within the 10cm to 200cm range will reduce the amount of interpolation between data points. Again, this will lead to a stronger set of data to which conclusions can be drawn. It would also be beneficial to determine the ground loop clearance at which no increased building heat loss is observed.

The method used to calculate the weekly ground loop heat fluxes was done to obtain reasonable values. However, it would be advantageous if a more precise method was developed to determine the expected daily ground loop heat fluxes. With the daily values calculated, the simulations can be run on a per day basis rather than a weekly basis. This would allow for more accurate results.

In summary, the intention of all recommended future work is to obtain stronger data to which an overall guideline for ground loop to foundation wall clearance can be developed.

5.2 Limitations

One of the major limitations of this research was the assumption of constant thermal conductivity for the test soil throughout the entire period of analysis. In reality, the thermal conductivity of the soil could vary quite significantly on a daily or weekly basis. The factor having the greatest impact on thermal conductivity is the moisture content of the soil. Wetter soils will have a much higher thermal conductivity than a drier soil, even if their soil composition is identical. For example, a dry fine sand could have a thermal conductivity of 1.28 W/(m•k) compared to a wet fine sand, which could have a thermal conductivity of 3.28 W/(m•k), an increase of 2.6 times. Soil temperature will also affect the thermal conductivity. Soils at temperatures below 0 ℃ will have a higher thermal conductivity than the same soil at temperatures above 0 ℃. Another limitation was the assumption that the thermal conductivity of the soil was the same for the entire test plot. The majority of on-site soils are non-homogenous, meaning there could be significant variance in its mineral composition. The variance in mineral composition would lead to non-uniform thermal properties of the soil surrounding the building, which would lead to Sides 1 through 5 of the building experiencing non-symmetrical heat loss. Also, intermittent environmental conditions such as rain and sunshine will cause the moisture content and temperature distribution of the soil to vary in a non-uniform way, only to be amplified by the heat flux of the ground loop.

A limitation regarding the ground loop was the assumption that the ground loop had the same constant output along the entire loop. In reality, the ground loop experiences a transient heat flux based on changing fluid and soil temperatures. The charging or de-charging of the loop into the ground would result in a variance in soil and fluid temperature along the ground loop, resulting in a non-uniform heat flux output along the ground loop. For example, the circulated refrigerant would be at its lowest temperature at the outlet of the fluid to air heat exchanger, which is the beginning of the loop. Initially the temperature difference between the soil and fluid would be greatest, leading to a high rate of heat transfer. However, the soil temperature would eventually decrease and approach the temperature of the fluid, leading to reduced rates of heat transfer.

Additionally, the method for calculating the weekly ground loop heat flux as well as using the average weekly ground loop heat flux rather than an hourly or daily value led to an inaccuracy in the results. Using a GSHP design software could aid in the more accurate calculation of the ground loop heat flux. It is the opinion of the author that although the results may have inaccuracies, the general trends observed would most likely remain true. On a high level, it can be presumed to be true that ground loops will affect soil temperature and therefore building heat loss. This highlights the importance of organizations such as PHIUS needing to develop a guideline for ground loop to foundation wall clearance to ensure the benefits of preheating ventilation air are not outweighed by the resulting increase in building heat loss.

Appendices

A1 - Zehnder ComfoFond-L Eco 350 Data Sheets and Brochure

Zehnder
Comfosystems
ComfoFond-L Eco

Zehnder truly believe that if you are creating a system solution then you need integrated products which are designed to fit together in order to give a refined, cohesive approach. Streamlining the number of suppliers and equipment sources, ensures that procurement is simplified, the number of potential deliveries reduced and the opportunity for error minimised. Choosing a system which is designed to fit together, simplifies and reduces installation time, improves system efficiencies and ensures availability of all components needed to do the job.

Zehnder's high quality products are designed to service the low energy house of tomorrow. At first level we offer **ComfoAir heat recovery units** for balanced ventilation and reduced heat loss in an air tight home.

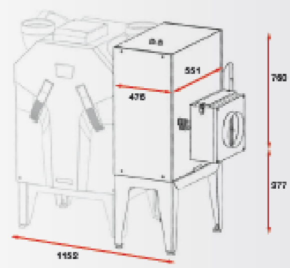
The **Zehnder ComfoFond-L Eco** sub-soil heat exchangers are designed to complement our heat recovery units. When connected to a **Zehnder ComfoAir 350 Luxe** or **550 Luxe** system, it augments the optimum comfort of the supply air to the dwelling throughout the year – even when the temperature falls below zero. This can help improve the efficiency of the heat recovery units as the incoming air requires less energy to meet the desired comfort temperature. By saving energy and providing an optimised indoor climate, benefits are felt by the building, the homeowner and the environment.

Physical specifications

ComfoFond-L Eco 350 (units shown with optional support frames)

Weight:	46kg
Installation:	Wall mounting or support frame (supplied separately)
Pre-heating capacity:	1854 W
Pre-cooling capacity:	1951 W
Liquid connection:	Standard ¾" straight connection
Air resistance:	31 Pa at 350 m^3/h
Insulation thickness:	25mm
Filter:	G4

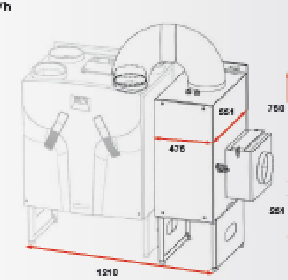
all dimensions shown are in millimetres



ComfoFond-L Eco 550 (units shown with optional support frames)

Weight:	47kg
Installation:	Wall mounting or support frame (supplied separately)
Pre-heating capacity:	2670 W
Pre-cooling capacity:	2784 W
Liquid connection:	Standard ¾" straight connection
Air resistance:	69 Pa at 550 m^3/h
Insulation thickness:	25mm
Filter:	G4

all dimensions shown are in millimetres

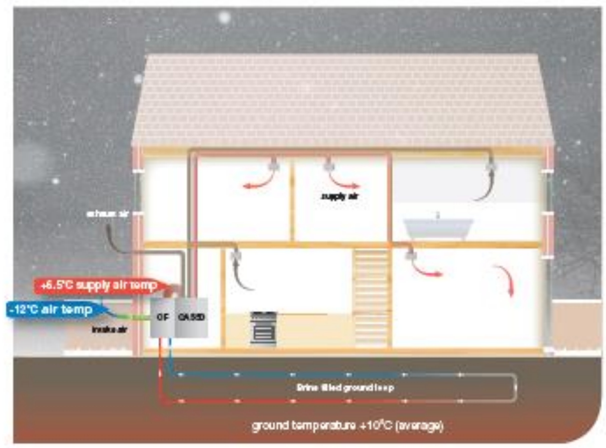


Sub-soil heat exchanger

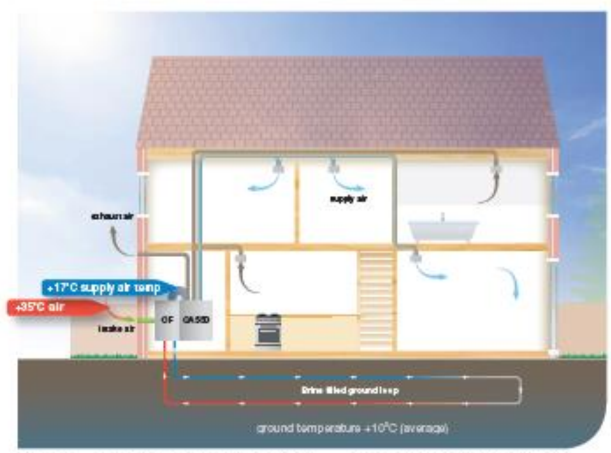
How does it work?
The Zehnder ComfoFond-L Eco earth-brine sub-soil heat exchanger uses the relatively constant annual temperature of the earth at a depth of one to one and a half metres. This 'passive store' of energy remains at a temperature of 8-12°C all year round and can be used to temper incoming supply air in winter and summer months.

- A brine filled ground loop is buried one to one and a half metres below the surface of the ground
- The integrated water pump moves the brine through the ground loop at 8 l/min
- The temperature of the brine is then modified by the temperature of the surrounding earth
- The brine loop is connected to the ComfoFond-L Eco which draws in air through an external wall
- The incoming air is filtered and passed through a liquid-to-air heat exchanger
- The tempering energy of the brine loop is passed to this air which is then delivered into the ComfoAir heat recovery unit for further tempering before being supplied to the habitable rooms of the home

Our expert technical team can offer advice as to the recommended length and diameter of the brine loop based on the individual details of your project.



Winter - external air temperature at -12°C
- airflow rate at 250m³/h
- brine solution flow rate at 8 l/min.
- supply air temperature at +6.5°C



Summer - external air temperature at +35°C
- airflow rate at 250m³/h
- brine solution flow rate at 8 l/min.
- supply air temperature at +17°C

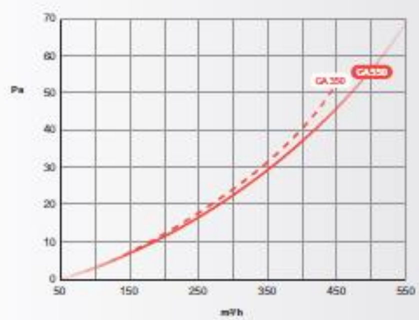
Key features

- Continuous fresh air supply for an optimum indoor climate
- Tempered supply air throughout the year
- Designed to integrate easily and effectively with the CA350 and CA550 from Zehnder's ComfoAir heat recovery range
- Operates automatically thanks to its integrated temperature sensor
- Smaller overall footprint thanks to parallel ground loop installation
- Ideal for use in high-water table and extremely effective in water bearing sand/gravel and granite soil types
- Exceptional energy efficiency due to utilisation of renewable energy from the ground
- Lessens the need for additional heating or cooling of the supply air
- The system is low maintenance and all serviceable parts are easily accessible

Performance statistics

The additional resistance of a ComfoFond-L Eco when used in conjunction with a ComfoAir 350 Luxe or 550 Luxe is shown here.

For example, when using the ComfoAir 350 Luxe at a flow rate of 350 m^3/h, the additional resistance of approximately 31 Pa (as shown in the graph) should be added to the total system pressure which is calculated based on the unit and the ducting.



Zehnder America sets a new precedent in heat recovery efficiency for cold climate ventilation

Zehnder has established a new Mechanical Ventilation with Heat Recovery (MVHR) benchmark with 99% apparent sensible effectiveness and 91% sensible recovery efficiency at -25°C. The testing was completed in November 2012 by Exova, a third party Home Ventilating Institute, in Alaska, one of the most extreme climates in the world.

The combined power consumption of the Zehnder ComfoAir unit when coupled with the ComfoFond-L was approximately 90 W/h. This is extremely low considering the beneficial heating load savings and comfort for the occupants.

By capturing the free stored energy in the ground to temper the air entering the MVHR unit, the fresh filtered air being supplied to the home was within 2-3 degrees of the comfort temperature. This mitigates uncomfortable cold draughts and provides a ground-breaking alternative to the common industry issue of unbalancing the system in cold weather by turning off the intake air to prevent the heat exchanger from freezing.

Thorsten Chlupp, homeowner, stated, "Alaska's extreme climate demands the use of only the highest performing components and strategies. Zehnder ComfoAir, combined with the ComfoFond-L sub-soil heat exchanger, has proven to be, by far, the best choice for us to meet our MVHR efficiency goals. Even at -50°F, the system maintained a two degree differential between the supply and return air."

More information on this case study can be found at **www.zehnderamerica.com**

Think system. Think unit. **Think ducting.**

Heat recovery is a system – the unit and the ducting – and it is the combination of these two elements that deliver ventilation into the home.

Ducting is just as important as the unit itself due to its impact on:

- Long term provision of indoor air quality
- Efficiency and airflow performance
- Speed and ease of installation
- Noise transfer around the home
- Occupant comfort and health

ComfoTube and **ComfoTube Flat 51** – our high-performance, semi-rigid air distribution systems - offer a whole host of benefits to developers, installers and homeowners from innovative features including:

- Radial designs giving individual runs to each room
- Flexible design removing the need for bend connection components
- Easy to be maintained and cleaned
- Lightweight and flexible yet still very, very strong - they can withstand the weight of a person without distorting and can even be buried in concrete
- No need for glues or sealants

Unique benefits - why choose the ComfoFond-L Eco?

- Frost-free permanent operation, even at external temperatures of less than -25°C (as shown in the case study opposite)
- ComfoFond-L Eco provides a closed loop system which offers improved hygiene over open loop versions
- The closed loop system offered by ComfoFond-L Eco delivers lower air resistance than an open loop system leading to lower running costs and enhanced efficiency
- All-in-one solution meaning reduced installation time – the pump, pressure tank and battery are mounted together in one unit
- Its high performance battery capacity provides class-leading air temperature ability
- Design and supply from one manufacturer ensures compatibility and ease of integration

Electrical specification

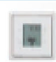
	ComfoFond-L Eco 350	ComfoFond-L Eco 550
Power supply	230V – 50Hz Class II	230V – 50Hz Class II
Maximum current	0.58 A	0.58 A
Maximum power consumption	70 W	70 W

Product codes



ComfoFond-L Eco 350 Left Handed	CF350L	ComfoAir 350 Luxe Left Handed[1]	CA350LLUXE
ComfoFond-L Eco 350 Right Handed	CF350R	ComfoAir 350 Luxe Right Handed[1]	CA350RLUXE
ComfoFond-L Eco 550 Left Handed	CF550L	ComfoAir 550 Luxe Left Handed[1]	CA550LLUXE
ComfoFond-L Eco 550 Right Handed	CF550R	ComfoAir 550 Luxe Right Handed[1]	CA550RLUXE

Control options and ancillaries





ComfoSense CS67 control unit with mounting box[1]	CC8	Support Frame for ComfoFond-L Eco 350	642 300 161
Dry Siphon 5/4"	990 201 330	Support Frame for ComfoFond-L Eco 550	642 300 166
G4 Filter	400 100 066		

ComfoFond-L Eco 350 with optional stand

[1] - Detailed literature containing technical data is available on request

Zehnder Comfosystems

Heat recovery ventilation from the experts in energy-efficient, healthy and comfortable indoor climate solutions.

With the continued focus and drive to build highly insulated dwellings, heat recovery ventilation remains the optimal solution for the provision of good indoor air quality throughout the year. Zehnder has more than 40 years' experience in the development and production of ventilation units and this experience forms the basis of well-considered products and systems which have numerous benefits; energy efficiency, comfort, health, ease of use and integration.

Why choose Zehnder Comfosystems?

Zehnder understands the requirements of high performance buildings and offers a full range of solutions to ensure the perfect indoor climate. **Some of the key benefits of choosing Zehnder as your solution partner are:**

- A full range of whole house heat recovery ventilation units
- Products that are independently tested and approved
- A range that covers all property sizes from smart, urban apartments to large, luxury dwellings
- ComfoAir MVHR units that meet stringent Passive House standards
- Year round comfort with true summer bypass as standard
- Outstanding specific fan power (SFP) and heat exchange efficiencies for real rewards in SAP
- A unique range of high performance ducting to complete the system solution
- An exceptional in-house technical team who can assist with all aspects of your project and are experts on all regulations and standards

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MCS611

A2 – Owens Corning FOAMULAR® 150 XPS Rigid Foam Insulation Data Sheet

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FOAMULAR® 150
Extruded Polystyrene (XPS) Rigid Foam Insulation

Product Data Sheet

Energy-Saving, Moisture Resistant XPS Insulation

ASTM C578 Type X, 15 psi minimum

Description

Owens Corning™ FOAMULAR® 150 extruded polystyrene (XPS) insulation is a closed cell, moisture-resistant rigid foam board well suited to meet the need for a wide variety of building applications.[3] FOAMULAR® 150 XPS insulation is ideal for many residential and commercial construction applications such as wall furring, perimeter/foundation, cavity wall, pre-cast concrete, crawl spaces, sheathing and other applications[3]. FOAMULAR® 150 XPS insulation is classified as a Type X product when tested in accordance with ASTM C578 and provides a long-term thermal performance of R-5 per inch.

Like all FOAMULAR® XPS products, FOAMULAR® 150 XPS insulation is made with Owens Corning's patented Hydrovac® process technology under strict quality control measures, which makes it highly resistant to moisture and permits the product to retain it's high R-value year after year even after prolonged exposure to moisture, and freeze/thaw cycling.

Key Features

- Excellent long-term stable insulating performance at R-5[1] per inch
- Exceptional moisture resistance, long-term durability
- Limited lifetime warranty[2]—maintains 90% of R-value and covers all ASTM C578 properties
- The only XPS foam to be GREENGUARD Children & Schools Certified℠
- The only XPS foam with certified recycled content—certified by Scientific Certification Systems (SCS) to contain a minimum 20% recycled content
- Will not corrode, rot or support mold growth
- Zero ozone depletion potential with 70% less global warming potential than our previous formula
- Reusable
- Lightweight, durable rigid foam panels are easy to handle and install
- Easy to saw, cut or score
- Versatile applications: sheathing, foundation walls, masonry cavity walls[3]
- Not for use in roofing. For roofing applications, use FOAMULAR® THERMAPINK® Extruded Polystyrene Insulation

Product type

- Minimum compressive strength of 15 psi
- Wide selection of sizes and thicknesses
- Available in square, tongue and groove or scored square edge
- Compliant with building codes and standards

Product Applications

High-performance FOAMULAR® 150 XPS insulation:

- Retards the transmission of water vapor and moisture in masonry walls
- Provides continuous insulation over steel stud framing, in insulated concrete sandwich panel walls, or in masonry unit cavity walls, or when used with non-penetrating, surface mounted furring systems over masonry or concrete walls
- Insulates and retains its properties in below grade perimeter and foundation applications, to complement the insulating sheathing envelope around the building framing
- FOAMULAR® 150 XPS insulation is ideal for below grade applications. Extruded polystyrene (XPS) is resistant to degradation from the components of common soils and will retain its insulating performance characteristics even after prolonged exposure to moisture.

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FOAMULAR® 150
Extruded Polystyrene (XPS) Rigid Foam Insulation

Product Data Sheet

- Provides a weather resistant barrier (when joints are sealed) to enhance the building resistance to air and moisture penetration.

Technical Information

This product is combustible. A protective barrier or thermal barrier is required as specified in the appropriate building code. For additional information, consult MSDS or contact Owens Corning World Headquarters at 1-800-GET-PINK®.

All construction should be evaluated for the necessity to provide vapor retarders. See current ASHRAE Handbook of Fundamentals.

FOAMULAR® 150 XPS Insulation is a non-structural material and must be installed on framing which is independently braced and structurally adequate to meet required construction and service loading conditions.

FOAMULAR® insulation can be exposed to the exterior during normal construction cycles. During that time some fading of color may begin due to UV exposure, and, if exposed for extended periods of time, some degradation or "dusting" of the polystyrene surface may begin. It is best if the product is covered within 60 days to minimize degradation. Once covered, the deterioration stops, and damage is limited to the thin top surface layers of cells. Cells below are generally unharmed and still useful insulation.

Typical Physical Properties[1]

FOAMULAR® 150 Extruded Polystyrene Insulation

Property	Test Method[2]	Value
Thermal Resistance[3], R-Value (180 day) minimum, hr•ft²•°F/Btu (RSI, °C•m²/W)		
@ 75°F (24°C) mean temperature	ASTM C518	
1" Thickness		5.0 (0.88)
1½" Thickness		7.5 (1.32
2" Thickness		10 (1.76)
2½" Thickness		12.5 (2.20)
3" Thickness		15 (2.64)
@ 40°F (4.4°C) mean temperature		
1" Thickness		5.4 (0.95)
1½" Thickness		8.1 (1.43)
2" Thickness		10.8 (1.90)
2½" Thickness		13.5 (2.38)
3" Thickness		16.2 (2.85)
Long Term Thermal Resistance, LTTR-Value[3] minimum hr•ft²•°F/Btu (RSI, °C•m²/W)		
@ 75°F (24°C) mean temperature	CAN/ULC S770-03	
1" Thickness		5.0 (0.88)
1½" Thickness		7.8 (1.37)
2" Thickness		10.6 (1.87)
2½" Thickness		13.4 (2.36)
3" Thickness		16.2 (2.85)
Compressive Strength[4], minimum psi (kPa)	ASTM D1621	15 (103)
Flexural Strength[5], minimum psi (kPa)	ASTM C203	60 (414)
Water Absorption[6], maximum % by volume	ASTM C272	0.10
Water Vapor Permeance[7], maximum perm (ng/Pa•s•m²)	ASTM E96	1.5 (86)
Dimensional Stability, maximum % linear change	ASTM D2126	2.0
Flame Spread[8,9]	ASTM E84	5
Smoke Developed[8,9,10]	ASTM E84	45-175
Oxygen Index[8], minimum % by volume	ASTM D2863	24
Service Temperature, maximum °F (°C)	—	165 (74)
Linear Coefficient of Thermal Expansion, in/in/°F (m/m/°C)	ASTM E228	3.5×10^{-5} (6.3×10^{-5})

1. Properties shown are representative values for 1" thick material, unless otherwise specified.
2. Modified as required to meet ASTM C578
3. R means the resistance to heat flow; the higher the value, the greater the insulation power. This insulation must be installed properly to get the marked R-value. Follow the manufacturer's instructions carefully. If a manufacturer's fact sheet is not provided with the material shipment, request this and review it carefully. R-values vary depending on many factors including the mean temperature at which the test is conducted, and the age of the sample at the time of testing. Because rigid foam plastic insulation products are not all aged in accordance with the same standards, it is useful to publish comparison R-value data. The R-value for FOAMULAR® XPS insulation is provided from testing at two mean temperatures, 40°F and 75°F, and from two aging (conditioning) techniques, 180 day real-time aged (as mandated by ASTM C578) and a method of accelerated aging sometimes called "Long Term Thermal Resistance" (LTTR) per CAN/ULC S770-03. The R-value at 180 day real-time age and 75°F mean temperature is commonly used to compare products and is the value printed on the product.
4. Values at yield or 10% deflection, whichever occurs first.
5. Value at yield or 5%, whichever occurs first.
6. Data ranges from 0.00 to value shown due to the level of precision of the test method.
7. Water vapor permeance decreases as thickness increases.
8. These laboratory tests are not intended to describe the hazards presented by this material under actual fire conditions.
9. Data from Underwriters Laboratories Inc.® classified. See Classification Certificate U-197.
10. ASTM E84 is thickness-dependent, therefore a range of values is given.

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FOAMULAR® 150
Extruded Polystyrene (XPS) Rigid Foam Insulation

Product Data Sheet

Product and Packaging Data
FOAMULAR® 150 Extruded Polystyrene Insulation

Material			Packaging					
Extruded polystyrene closed cell foam, ASTM C578 Type X, 15 psi minimum			Shipped in poly-wrapped units with individually wrapped or banded bundles.					
Thickness (in)	Product Dimensions Thickness (in) x Width (in) x Length (in)	Pallet (Unit) Dimensions (typical) Width (ft) x Length (ft) x Height (ft)	Square feet per Pallet	Board feet per Pallet	Bundles per Pallet	Pieces per Bundle	Pieces per Pallet	Edges
1	1 x 24 x 96	4 x 8 x 8	3,072	3,072	8	24	192	Square Edge, Scored Square Edge, Tongue & Groove
	1 x 24 x 96	4 x 8 x 8	3,072	3,072	8	24	192	
	1 x 48 x 96	4 x 8 x 8	3,072	3,072	8	12	96	
	1 x 48 x 96 (Half unit)	4 x 8 x 4	1,536	1,536	4	12	48	
	1 x 48 x 108	4 x 9 x 8	3,456	3,456	8	12	96	
1½	1.5 x 24 x 96	4 x 8 x 8	2,048	3,072	8	16	128	
	1.5 x 48 x 96	4 x 8 x 8	2,048	3,072	8	8	64	
2	2 x 24 x 96	4 x 8 x 8	1,536	3,072	8	12	96	
	2 x 48 x 96	4 x 8 x 8	1,536	3,072	8	6	48	
2½	2.5 x 48 x 96	4 x 8 x 8	1,152	2,830	4	9	36	
3	3 x 24 x 96	4 x 8 x 8	1,024	3,072	8	8	64	
	3 x 48 x 96	4 x 8 x 8	1,024	3,072	8	4	32	

1. Available lengths and edge configurations vary by thickness. See www.foamular.com for current offerings. Other sizes may be available upon request. Consult your local Owens Corning representative for availability.

Standards, Codes Compliance

- Meets ASTM C578 Type X
- UL Classified. A copy of UL Classification Certificate U-197 is available at www.foamular.com
- See ICC-ES ESR-1061 at www.icc-es.org
- ASTM E119 Fire Resistance Rated Wall Assemblies. See www.foamular.com for details.
- Meets California Quality Standards; HUD UM #71A
- Compliance verification by RADCO (AA-650)

Certifications and Sustainable Features of FOAMULAR® XPS Insulation

- FOAMULAR® XPS insulation is reusable
- FOAMULAR® XPS insulation is made with a zero ozone depletion formula
- Certified by Scientific Certification Systems to contain a minimum of 20% pre-consumer recycled polystyrene
- Certified to meet indoor air quality standards under the stringent GREENGUARD Indoor Air Quality Certification Program℠, and the GREENGUARD Children & Schools Certification Program℠
- Qualified as an ENERGY STAR® product, under the U.S. Environmental Protection Agency and the U.S. Department of Energy
- Approved under the National Association of Home Builders (NAHB) Research Center Green Seal of Approval
- Utilizing FOAMULAR® XPS insulation can help builders achieve green building certifications including the Environmental Protection Agency's ENERGY STAR®, the National Association of Home Builders' National Green Building certification, and the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) certification
- FOAMULAR® XPS insulation may qualify for The Buy American provision of the American Recovery and Reinvestment Act (ARRA)

FOAMULAR® 150

Extruded Polystyrene (XPS) Rigid Foam Insulation

Product Data Sheet

Environmental and Sustainability

Owens Corning is a worldwide leader in building material systems, insulation and composite solutions, delivering a broad range of high-quality products and services. Owens Corning is committed to driving sustainability by delivering solutions, transforming markets and enhancing lives. More information can be found at www.sustainability.owenscorning.com.

Warranty

FOAMULAR® XPS Insulation limited lifetime warranty maintains 90% of its R-value for the lifetime of the building and covers all ASTM C578 properties. See actual warranty for complete details, limitations and requirements at www.foamular.com or www.owenscorningcommercial.com.

Notes

1. R means the resistance to heat flow; the higher the R-value, the greater the insulating power.
2. See actual warranty for complete details, limitations and requirements.
3. Not for use in roofing. For roofing applications, use FOAMULAR® THERMAPINK® Extruded Polystyrene Insulation.

All products described here may not be available in all geographic markets. Consult your local sales office representative for more information.

For more information on the Owens Corning family of building products, contact your Owens Corning dealer, call 1-800-GET-PINK®, or access our web sites: www.foamular.com and www.owenscorning.com.

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This NAHB Research Center Green Approved mark is your assurance that a product is eligible for points toward National Green Building Certification. Visit www.GreenApprovedProducts.com for details.

LEED is a registered trademark of the U.S. Green Building Council.

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A3 - Simulation Results Data

Table 21: Side 1&2 heat loss - soil 1

	No GL	10cm	50cm	100cm	200cm
	Q	Q	Q	Q	Q
Week	[W]	[W]	[W]	[W]	[W]
0	93	488	323	217	127
1	83	472	318	212	119
2	80	538	335	220	119
3	78	445	324	219	121
4	93	577	361	243	138
5	100	663	403	266	148
6	88	594	397	261	140
7	87	551	389	261	141
8	76	440	349	243	132
9	89	491	356	253	146
10	83	517	355	249	141
11	74	414	327	234	134
12	77	402	313	230	136
13	72	389	298	220	131
14	64	338	273	204	123
15	61	301	251	192	118
16	67	303	245	191	123
17	61	291	231	180	116
18	53	250	210	164	106
19	50	208	189	153	102
20	54	216	183	150	103
21	44	156	155	131	92
22	42	127	136	120	87
23	40	105	118	109	83
24	38	63	96	96	78
25	40	87	92	92	77
26	33	34	71	77	68
27	23	-28	38	55	55
28	29	-22	30	52	58
29	30	-9	26	48	56
30	27	5	24	42	51
31	23	-16	16	34	44
32	19	-26	8	27	38
33	26	-31	8	29	43
34	25	-9	10	27	41
35	27	33	22	32	41

36	27	7	22	32	40
37	33	45	35	39	45
38	37	93	54	48	48
39	35	96	62	51	47
40	31	97	65	51	43
41	40	128	83	64	52
42	38	152	93	68	51
43	44	168	109	79	58
44	46	185	120	86	60
45	54	200	136	98	70
46	56	262	157	109	73
47	73	362	206	140	92
48	60	348	212	137	81
49	69	384	238	156	93
50	78	467	276	179	105
51	75	479	294	189	105
52	89	483	318	211	122
53	93	488	324	217	127
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	56	256	187	139	91

Table 22: Side 3&4 heat loss - soil 1

	No GL	10cm	50cm	100cm	200cm
Week	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**
0	140	553	388	276	179
1	125	531	377	267	167
2	120	598	395	274	165
3	118	501	382	272	166
4	140	646	428	305	191
5	151	738	476	333	205
6	133	661	465	323	191
7	131	616	455	322	193
8	114	496	409	298	178
9	133	555	421	314	199
10	124	580	418	307	191
11	112	469	384	288	180
12	115	457	371	284	184
13	108	442	352	271	176
14	96	384	322	251	163
15	91	345	297	236	157
16	101	350	295	238	165

17	92	335	277	224	155
18	79	287	250	203	140
19	75	243	227	189	134
20	81	252	222	188	138
21	66	186	188	163	121
22	62	155	166	150	115
23	60	131	147	137	110
24	56	86	122	122	103
25	59	111	119	118	103
26	49	53	92	99	90
27	34	-16	53	72	72
28	43	-7	47	71	77
29	44	6	43	66	75
30	40	19	40	58	68
31	34	-4	29	48	59
32	28	-16	18	38	51
33	38	-19	22	44	59
34	37	3	23	41	56
35	40	48	37	47	57
36	41	21	37	47	56
37	50	63	53	58	64
38	55	115	75	69	69
39	52	117	83	71	66
40	46	116	84	69	61
41	60	152	107	87	74
42	57	177	117	90	72
43	66	196	137	105	82
44	68	214	149	113	86
45	81	234	169	131	100
46	84	299	193	143	104
47	110	412	253	184	132
48	90	391	253	175	114
49	103	432	285	200	131
50	117	523	329	229	147
51	112	534	348	238	146
52	133	546	380	268	171
53	140	553	388	276	179
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	84	294	226	176	124

Table 23: Side 5 heat loss - soil 1

Week	No GL Q [W]	10cm Q [W]	50cm Q [W]	100cm Q [W]	200cm Q [W]
0	119	270	254	226	188
1	120	273	260	230	190
2	120	286	267	235	191
3	120	279	271	239	193
4	121	297	277	243	195
5	121	316	289	250	198
6	122	316	297	256	200
7	122	313	301	260	203
8	123	301	301	263	206
9	123	306	302	266	208
10	123	315	306	269	210
11	124	305	307	271	212
12	124	302	305	272	214
13	124	301	305	273	216
14	125	296	303	274	218
15	125	290	300	274	219
16	125	288	298	273	220
17	125	287	296	272	221
18	125	282	293	272	221
19	125	274	289	270	222
20	125	272	285	268	222
21	125	263	281	266	222
22	125	256	275	263	222
23	125	249	270	260	221
24	125	240	263	256	220
25	124	239	258	253	219
26	124	230	252	249	218
27	124	218	245	244	217
28	123	212	237	239	215
29	123	210	232	235	213
30	123	209	227	231	211
31	122	203	223	227	209
32	122	199	218	224	207
33	121	193	214	220	205
34	121	193	210	216	203
35	121	196	208	213	201
36	120	191	206	211	199
37	120	192	204	208	197
38	119	198	204	207	196

39	119	198	204	206	194
40	119	198	204	205	193
41	119	200	205	204	191
42	118	204	206	204	190
43	118	206	208	204	189
44	118	209	210	204	189
45	118	211	211	205	188
46	118	220	215	206	188
47	118	235	222	209	188
48	118	240	228	212	188
49	118	246	234	216	194
50	118	261	242	220	193
51	119	269	251	225	194
52	119	272	257	229	195
53	119	273	258	230	195
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	122	250	254	238	204

Table 24: Side 1&2 heat loss - soil 2

	No GL	**10cm**	**50cm**	**100cm**	**200cm**
Week	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**
0	146	191	176	165	154
1	135	179	164	154	143
2	136	189	170	158	145
3	128	167	156	147	136
4	149	204	184	171	158
5	164	228	204	189	173
6	149	205	187	174	160
7	143	194	178	167	154
8	123	160	150	142	132
9	136	178	164	155	145
10	134	180	164	154	143
11	118	152	142	135	126
12	117	149	139	133	125
13	111	142	132	126	118
14	100	126	118	113	106
15	93	115	109	104	99
16	97	119	113	108	103
17	91	113	106	102	97
18	81	99	94	90	86
19	75	88	85	83	79

20	78	92	88	85	82
21	65	73	72	71	69
22	60	65	65	64	63
23	56	59	59	59	58
24	49	48	50	51	51
25	53	55	55	55	55
26	43	40	42	44	45
27	29	19	24	27	29
28	33	24	28	31	33
29	37	29	32	34	36
30	37	32	34	35	36
31	32	26	29	30	32
32	28	21	24	25	27
33	33	24	28	30	32
34	35	30	31	32	34
35	41	41	40	40	40
36	39	36	38	38	39
37	48	49	48	48	48
38	56	63	60	58	56
39	56	63	61	59	57
40	53	61	59	56	54
41	63	73	69	67	64
42	64	78	73	69	66
43	71	85	80	77	73
44	74	90	84	80	76
45	82	99	93	89	85
46	89	114	104	98	92
47	115	150	136	127	119
48	104	138	126	118	109
49	114	151	137	129	119
50	128	174	157	146	135
51	129	176	159	148	136
52	139	184	169	158	147
53	146	191	176	165	154
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	87	108	101	97	91

Table 25: Side 3&4 heat loss - soil 2

Week	No GL Q [W]	10cm Q [W]	50cm Q [W]	100cm Q [W]	200cm Q [W]
0	221	269	253	243	230
1	204	251	236	226	214
2	206	262	243	230	216
3	193	236	224	215	203
4	226	284	263	250	236
5	247	316	292	276	259
6	225	285	267	254	238
7	217	271	255	243	229
8	185	225	215	207	197
9	206	251	237	227	216
10	202	251	236	225	212
11	178	215	205	198	188
12	176	211	202	194	186
13	167	201	191	184	176
14	150	179	171	166	158
15	140	164	158	153	147
16	147	171	164	159	154
17	138	161	155	150	144
18	122	141	137	133	128
19	113	127	124	122	118
20	117	133	129	125	122
21	98	108	106	105	102
22	90	97	96	95	94
23	84	88	89	88	87
24	74	73	75	76	76
25	80	83	82	82	82
26	65	62	65	66	67
27	43	34	39	42	44
28	50	41	45	48	50
29	55	48	51	53	55
30	55	51	53	54	55
31	49	42	45	47	49
32	42	35	38	39	41
33	49	41	45	46	49
34	52	48	49	50	52
35	61	62	62	61	61
36	59	57	58	59	59
37	72	74	73	73	72
38	85	93	89	87	85

39	85	93	90	88	86
40	81	89	87	84	82
41	95	106	102	100	97
42	97	112	107	103	99
43	107	123	118	114	110
44	112	130	124	119	115
45	125	143	137	133	128
46	135	161	151	145	139
47	174	211	197	188	179
48	158	194	182	173	164
49	172	212	198	189	179
50	194	243	226	214	202
51	195	245	228	217	204
52	210	258	243	232	219
53	221	269	253	243	230
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	132	154	147	142	137

Table 26: Side 5 heat loss - soil 2

	No GL	**10cm**	**50cm**	**100cm**	**200cm**
Week	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**
0	377	415	412	404	394
1	383	422	419	412	401
2	389	432	428	420	408
3	394	437	434	426	414
4	399	445	441	432	420
5	406	456	451	441	427
6	413	464	460	450	436
7	419	471	468	458	443
8	423	474	472	462	448
9	426	478	474	465	452
10	429	482	479	469	456
11	432	483	481	472	459
12	434	484	482	473	461
13	435	485	482	474	462
14	435	483	481	474	462
15	435	481	479	473	461
16	434	479	477	471	460
17	432	477	475	469	458
18	431	474	472	466	456
19	429	469	468	463	454

20	426	465	464	459	451
21	423	460	459	455	447
22	420	454	454	450	443
23	416	448	448	444	438
24	411	441	441	438	433
25	407	435	434	432	427
26	402	427	427	426	421
27	397	419	419	419	415
28	391	411	411	411	408
29	385	402	403	403	401
30	380	396	397	397	395
31	375	391	391	391	389
32	371	385	385	385	384
33	366	379	379	379	378
34	361	374	374	374	373
35	358	370	370	370	369
36	355	366	366	366	365
37	352	363	363	363	362
38	350	362	362	361	359
39	348	362	361	360	358
40	348	361	361	360	357
41	347	361	360	359	357
42	347	362	361	360	357
43	347	364	363	361	357
44	348	366	364	362	358
45	349	367	366	363	359
46	350	371	369	366	361
47	352	377	374	370	364
48	357	383	381	376	369
49	361	390	387	382	374
50	366	398	395	389	380
51	371	407	404	397	387
52	377	414	411	404	394
53	377	415	412	405	394
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	390	421	419	415	408

Table 27: Side 1&2 heat loss - soil 3

	No GL	10cm	50cm	100cm	200cm
	Q	Q	Q	Q	Q
Week	[W]	[W]	[W]	[W]	[W]
0	128	237	196	169	141
1	118	226	187	160	132
2	118	244	193	163	133
3	114	215	184	158	130
4	131	264	209	178	148
5	141	294	231	194	159
6	130	268	219	184	149
7	127	255	213	181	147
8	113	214	188	163	133
9	125	236	198	173	145
10	120	238	196	169	140
11	109	202	177	155	129
12	110	199	173	153	129
13	104	190	164	145	123
14	95	168	149	132	112
15	89	154	138	124	106
16	94	157	140	127	110
17	88	149	131	118	103
18	79	131	118	107	93
19	74	116	108	99	88
20	77	119	108	100	89
21	66	95	91	86	78
22	62	84	83	79	72
23	59	75	75	73	69
24	54	59	65	65	62
25	55	67	66	65	63
26	47	46	53	54	54
27	35	20	34	38	41
28	40	24	35	40	44
29	41	28	36	40	44
30	38	31	35	38	42
31	34	22	30	33	37
32	30	17	24	28	32
33	36	19	28	33	37
34	36	26	30	33	37
35	39	40	37	38	40
36	39	33	37	38	40
37	46	49	46	46	47
38	51	66	57	54	53

39	51	67	60	55	53
40	48	66	59	54	50
41	57	81	71	64	60
42	57	88	74	66	60
43	63	98	84	75	67
44	66	104	89	79	70
45	74	115	99	89	79
46	79	135	110	96	84
47	99	178	141	122	106
48	88	167	135	115	96
49	98	185	150	128	107
50	110	217	171	144	120
51	109	220	176	148	121
52	122	232	191	163	136
53	128	237	196	169	141
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	80	135	116	104	90

Table 28: Side 3&4 heat loss - soil 3

	No GL	**10cm**	**50cm**	**100cm**	**200cm**
Week	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**	**Q [W]**
0	194	309	268	239	209
1	179	292	254	225	195
2	178	311	260	228	195
3	173	280	249	221	191
4	198	338	283	250	217
5	213	375	311	272	234
6	196	342	293	257	218
7	192	328	285	252	215
8	171	278	252	226	194
9	189	306	269	243	212
10	181	306	264	236	204
11	165	264	239	216	188
12	166	261	235	214	188
13	157	249	223	203	179
14	143	222	202	185	163
15	135	204	188	174	155
16	142	210	193	179	161
17	132	198	181	167	150
18	118	175	162	150	135
19	112	157	149	140	127

20	115	162	151	142	130
21	99	131	128	122	113
22	93	117	117	112	105
23	88	107	107	105	100
24	80	88	94	94	91
25	83	96	96	95	92
26	71	71	78	80	79
27	52	38	52	57	59
28	59	45	56	61	65
29	61	49	57	62	66
30	58	51	55	58	62
31	51	40	47	51	55
32	45	32	40	43	47
33	53	37	47	51	56
34	54	44	48	52	56
35	59	60	58	58	60
36	58	53	57	58	60
37	69	73	70	70	70
38	77	93	85	81	79
39	76	94	87	82	79
40	72	92	84	79	75
41	86	112	101	94	89
42	85	119	105	96	89
43	95	132	118	108	100
44	99	140	125	114	105
45	112	156	140	129	118
46	119	178	153	138	125
47	150	233	196	176	158
48	133	217	184	163	143
49	148	240	205	181	159
50	166	279	232	204	178
51	165	282	237	208	179
52	185	300	260	230	200
53	193	309	268	239	209
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	121	179	161	148	133

Table 29: Side 5 heat loss - soil 3

	No GL	10cm	50cm	100cm	200cm
	Q	Q	Q	Q	Q
Week	[W]	[W]	[W]	[W]	[W]
0	302	374	366	350	332
1	303	378	370	354	335
2	305	385	375	358	338
3	306	385	379	361	341
4	308	393	383	365	343
5	310	402	390	370	346
6	312	405	396	375	350
7	314	408	400	379	353
8	316	407	402	382	357
9	318	411	404	384	359
10	319	416	407	387	362
11	321	414	409	390	364
12	322	415	410	391	366
13	323	416	411	393	368
14	324	415	411	393	369
15	325	414	410	394	370
16	325	413	410	394	371
17	325	413	409	394	371
18	325	411	408	393	371
19	325	408	406	392	371
20	325	407	404	391	371
21	325	403	402	389	370
22	324	399	399	387	369
23	323	396	395	385	368
24	322	391	392	382	366
25	321	389	388	379	364
26	320	384	384	376	362
27	318	378	379	373	360
28	317	373	375	369	357
29	315	369	370	365	354
30	313	366	367	362	352
31	311	362	363	358	349
32	310	358	359	355	346
33	308	354	355	351	344
34	306	351	352	348	341
35	305	350	349	346	339
36	303	346	347	343	336
37	302	345	344	341	334
38	301	345	343	339	332

39	300	344	342	338	331
40	299	343	341	336	329
41	298	343	341	335	328
42	297	343	341	335	327
43	297	344	341	335	326
44	296	344	341	335	326
45	296	345	342	335	326
46	296	348	343	336	326
47	296	353	346	337	326
48	297	356	350	339	327
49	298	359	353	342	328
50	299	366	357	345	330
51	300	370	362	348	332
52	301	374	367	352	334
53	302	375	367	352	335
	Q [W]	Q [W]	Q [W]	Q [W]	Q [W]
Average Loss	311	379	375	364	348

Table 30: Side 1&2 heat loss - soil 4

	No GL	**10cm**	**50cm**	**100cm**	**200cm**
Week	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**
0	155	205	188	177	165
1	140	187	171	161	149
2	143	202	181	168	154
3	129	170	157	149	139
4	160	222	200	186	171
5	178	251	225	209	190
6	154	215	195	182	167
7	146	198	182	170	157
8	118	153	143	136	127
9	140	184	169	160	149
10	139	189	172	161	148
11	115	148	138	131	123
12	114	147	137	130	122
13	108	140	130	123	115
14	96	122	114	109	102
15	88	109	103	98	93
16	94	116	109	105	99
17	88	110	103	98	93
18	76	93	88	85	80
19	69	81	78	75	72

20	74	88	83	80	77
21	59	65	64	63	61
22	53	56	56	55	55
23	49	50	51	50	50
24	40	36	38	39	41
25	49	50	50	50	49
26	36	30	32	34	36
27	18	4	9	13	16
28	25	13	18	20	23
29	32	23	26	28	30
30	33	28	30	31	32
31	27	20	23	24	26
32	21	13	16	18	20
33	27	17	21	23	25
34	31	26	28	29	30
35	39	41	40	40	39
36	35	31	33	33	34
37	47	49	48	47	46
38	57	67	63	61	58
39	56	64	61	59	57
40	53	62	59	57	54
41	63	75	71	68	65
42	65	81	76	72	68
43	71	88	82	78	74
44	75	93	87	83	78
45	84	102	96	92	87
46	94	122	112	105	98
47	126	167	153	143	132
48	110	148	135	126	116
49	120	161	147	138	127
50	138	191	172	160	147
51	138	191	173	161	148
52	145	194	178	167	154
53	155	205	188	177	165
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	87	109	102	97	91

Table 31: Side 3&4 heat loss - soil 4

	No GL	10cm	50cm	100cm	200cm
	Q	Q	Q	Q	Q
Week	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]
0	235	288	271	260	246
1	212	262	246	235	222
2	216	278	258	244	228
3	195	239	226	217	206
4	242	308	286	271	254
5	268	346	321	303	283
6	233	297	278	264	248
7	220	276	260	248	233
8	178	216	206	198	189
9	211	259	244	233	221
10	209	263	246	234	221
11	173	209	199	192	183
12	172	208	197	190	181
13	162	197	187	180	171
14	145	173	165	159	152
15	132	156	149	145	139
16	142	166	159	154	148
17	133	157	150	145	139
18	115	133	128	125	120
19	104	117	114	111	108
20	111	127	123	119	115
21	89	96	95	93	92
22	80	84	84	83	82
23	74	76	76	76	76
24	61	57	59	60	61
25	74	76	76	75	75
26	54	48	51	53	54
27	27	13	18	22	25
28	38	26	30	33	36
29	48	40	43	44	47
30	51	46	47	48	49
31	42	34	37	38	40
32	32	24	27	29	31
33	41	31	35	37	40
34	47	42	44	45	46
35	60	62	61	60	60
36	53	49	51	52	53
37	71	73	72	71	71
38	87	97	94	91	88

39	84	94	91	88	86
40	80	90	87	84	82
41	96	109	105	101	98
42	99	116	110	106	102
43	108	125	120	116	111
44	113	133	126	122	117
45	127	147	140	136	131
46	142	172	162	155	147
47	191	235	220	210	198
48	166	206	193	184	174
49	182	226	211	202	190
50	209	265	246	234	219
51	209	265	247	234	220
52	219	272	255	244	230
53	235	288	271	260	246
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	131	155	148	143	137

Table 32: Side 5 heat loss - soil 4

	No GL	**10cm**	**50cm**	**100cm**	**200cm**
Week	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**
0	397	450	447	437	423
1	410	465	462	452	437
2	424	484	480	468	453
3	432	490	487	477	462
4	440	505	500	488	472
5	456	528	522	509	490
6	471	545	541	527	508
7	480	553	549	537	518
8	483	551	548	538	521
9	482	549	546	535	519
10	487	556	552	542	525
11	489	554	551	542	527
12	486	548	545	537	523
13	484	544	541	533	520
14	480	537	534	527	515
15	475	527	525	519	508
16	468	517	515	510	499
17	463	511	509	503	493
18	457	502	500	495	486
19	449	489	488	484	476

20	440	478	477	473	466
21	432	466	465	462	456
22	422	452	451	449	444
23	411	437	436	435	431
24	399	420	420	420	417
25	388	407	406	406	403
26	377	393	393	393	391
27	366	376	376	378	377
28	351	358	358	360	360
29	340	344	345	346	347
30	332	336	336	338	338
31	325	327	327	329	330
32	317	318	319	320	321
33	308	307	308	310	311
34	302	301	301	303	304
35	298	299	299	300	301
36	295	296	296	297	297
37	292	293	293	294	294
38	292	297	296	296	295
39	295	301	301	300	298
40	297	305	304	303	301
41	298	308	307	305	303
42	302	315	314	311	308
43	306	321	320	317	313
44	311	328	326	323	319
45	314	333	331	328	323
46	321	344	341	337	331
47	330	360	357	351	342
48	346	380	377	370	360
49	356	394	391	384	373
50	370	415	411	402	389
51	385	435	431	421	407
52	396	449	445	435	421
53	397	450	447	437	423
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	388	421	419	415	407

Table 33: Side 1&2 heat loss - soil 5

Week	No GL Q [W/m2]	10cm Q [W/m2]	50cm Q [W/m2]	100cm Q [W/m2]	200cm Q [W/m2]
0	142	212	188	172	154
1	132	199	176	161	143
2	133	214	184	165	145
3	125	186	168	154	137
4	146	231	198	178	158
5	160	259	221	198	174
6	145	232	203	183	161
7	140	218	193	175	155
8	120	178	162	150	134
9	133	198	176	162	146
10	130	202	177	161	143
11	115	168	153	142	128
12	114	164	149	138	126
13	108	157	141	131	119
14	97	138	126	118	107
15	90	125	116	108	100
16	95	129	119	112	104
17	89	123	113	105	97
18	79	107	99	93	86
19	73	93	89	85	80
20	75	98	91	87	82
21	63	76	75	72	69
22	58	67	66	65	63
23	55	59	60	59	58
24	48	46	49	50	51
25	52	55	54	54	54
26	42	37	41	43	44
27	28	13	21	25	29
28	32	18	25	28	32
29	35	24	29	32	35
30	35	28	31	33	35
31	31	21	26	28	31
32	26	16	21	23	26
33	32	19	25	27	31
34	33	26	29	30	33
35	39	40	39	38	38
36	38	33	36	37	37
37	46	48	47	46	46
38	54	65	60	57	55

39	54	66	61	58	55
40	52	64	59	56	53
41	61	77	71	67	63
42	62	83	75	70	65
43	69	91	83	77	72
44	72	97	88	82	76
45	80	106	97	91	84
46	87	125	110	100	91
47	112	165	144	131	118
48	101	154	135	122	109
49	111	168	147	133	119
50	125	196	169	152	134
51	125	198	172	154	136
52	136	206	181	165	147
53	142	212	188	172	154
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	85	117	107	99	91

Table 34: Side 3&4 heat loss - soil 5

	No GL	10cm	50cm	100cm	200cm
Week	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**	**Q [W/m2]**
0	216	290	266	248	229
1	199	271	248	232	213
2	201	286	256	236	215
3	189	254	236	221	203
4	220	310	278	257	235
5	241	346	309	284	258
6	220	312	283	262	237
7	211	295	270	251	229
8	181	243	228	214	198
9	201	271	249	233	216
10	197	273	248	231	212
11	174	230	216	204	189
12	172	226	211	200	186
13	163	215	200	189	176
14	146	190	179	170	159
15	136	174	164	157	147
16	143	181	170	163	153
17	134	171	160	153	144
18	118	149	141	135	128
19	109	132	128	123	118

20	114	138	132	127	121
21	95	110	108	106	102
22	88	97	97	95	93
23	82	88	89	88	87
24	72	71	74	75	76
25	78	82	81	81	81
26	63	58	63	64	66
27	42	27	35	39	43
28	49	35	41	45	49
29	53	42	47	50	53
30	53	46	49	50	53
31	47	37	42	44	47
32	40	30	34	36	39
33	48	35	41	43	47
34	50	43	46	47	50
35	59	60	59	58	58
36	57	53	56	56	57
37	70	72	71	70	70
38	82	94	89	85	83
39	82	94	90	86	83
40	78	91	87	83	80
41	92	110	103	99	95
42	94	117	108	103	97
43	104	128	120	114	108
44	109	136	127	120	113
45	121	149	140	133	126
46	131	171	156	147	137
47	169	226	204	190	176
48	153	209	190	176	162
49	168	228	207	193	177
50	189	264	237	219	200
51	190	267	240	222	202
52	205	280	255	238	219
53	216	290	266	248	229
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	128	163	152	144	136

Table 35: Side 5 heat loss - soil 5

Week	No GL Q [W/m2]	10cm Q [W/m2]	50cm Q [W/m2]	100cm Q [W/m2]	200cm Q [W/m2]
0	348	402	398	387	372
1	353	410	405	394	378
2	358	420	414	402	385
3	363	424	420	408	391
4	367	433	427	415	397
5	373	445	438	424	404
6	379	453	447	433	412
7	384	459	454	440	419
8	388	461	458	444	424
9	390	465	460	447	427
10	393	469	464	451	431
11	396	469	466	454	434
12	397	470	467	455	436
13	398	470	467	455	437
14	399	468	465	455	437
15	399	465	463	453	437
16	398	463	461	451	435
17	397	461	458	449	434
18	396	457	455	447	432
19	394	452	451	443	430
20	392	448	447	440	427
21	389	442	442	435	424
22	386	436	436	430	420
23	383	430	429	425	415
24	379	422	422	418	410
25	375	416	416	412	404
26	371	408	409	406	399
27	367	399	400	399	393
28	361	391	392	391	387
29	356	384	384	384	380
30	352	378	378	377	374
31	348	372	372	372	369
32	344	366	366	366	364
33	340	359	360	360	358
34	336	355	355	355	354
35	333	352	351	351	342
36	330	348	348	348	345
37	327	345	345	344	343
38	325	345	344	343	340

39	324	344	343	342	339
40	324	344	343	341	338
41	323	345	343	341	337
42	323	346	345	342	338
43	323	348	346	343	338
44	323	350	348	344	339
45	324	351	350	346	340
46	325	356	353	348	341
47	327	363	359	352	344
48	331	369	366	359	349
49	334	376	372	364	354
50	338	386	381	371	359
51	343	395	390	379	366
52	348	402	398	387	372
53	348	403	399	388	373
	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]	Q [W/m2]
Average Loss	360	405	403	396	386

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