Results in Engineering 7 (2020) 100141

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.editorialmanager.com/rineng/Default.aspx

# Numerical calculation of heat losses for crawl space foundation at different locations in Sweden

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ARTICLE INFO

*Keywords:*
Crawl space
Heat losses
Foundation

ABSTRACT

Crawl space is one of the most common foundation types in Sweden, and over five hundred thousand family houses have this type of foundation. This study determines how the heat losses variate at six different locations in Sweden from the south to the north. The average heat for a year varied between 1.76 and 3.07 $W/m^2$. The maximum heat flux was 4.43 $W/m^2$ in Kiruna, while Falsterbo has a maximum heat flux of 3.18 $W/m^2$. Minimum heat flux varied between 0.43 and 1.38 $W/m^2$. A sensitivity study of the important parameter showed that the temperature is the most important parameter with a decrease in average heat flux of 0.15 $W/m^2$ per degree increase in air temperature. Snow depth and snow days are less sensitive and give less than a 2.3% decrease for the average heat flux with a variation of ±50% and ±20 days, respectively.

## 1. Introduction

In Sweden, over five hundred thousand single-family houses have crawl spaces [1]. Heat losses through crawl spaces foundation are seldom study and only a few previous studies can be found in the literature. Son et al. have studies how large the heat losses from a hot water floor heating system to Crawl spaces [2]. Their research didn't focus on the heat losses from the foundation, but they find out even is the water pipe is insulated, the heat losses are still high to the crawl space. Salo et al. [3] developed a model that can predict the temperature field around crawl space, but the goal was to predict the hygrothermal conditions inside the crawl space for prediction of mould growth. Perrealut et al. [4] study how thermal insulation affects the permafrost under the crawl space didn't look specific into the heat losses through the foundation. Risberg et al. [5] developed a model that predicts the impacts of snow and soil freezing on heat losses for four different foundation types where crawl space was one of the types. Other studies mainly focused on temperature and relative humidity in the space to be able to predict mould growth. For example, Matilainen et al. [6] that studies how ground cover affects the mould growth in the crawl space and Høegh [7], who created a model to determine relative humidity dependent on changes in the construction. Modeling of crawl spaces has also been performed by Keskikuru et al. [8] that predicted the mould growth with a numerical model that was able to predict the temperature and relative humidity, but they didn't calculate the heat losses. To summarise, studies of the heat losses through crawl space foundations are very sparse, with only a few studies performed earlier.

To predict heat losses through the crawl space foundation, often, 1D calculation is used. These calculations don't include all the necessary details to predict the correct heat losses through the foundation. Previous studies by Risberg et al. [5] have shown that 1D methods by the ISO 13370 standard shown a significant deviation compared to a more detailed 3D model that included soil freezing and snow for cold periods with snow. For periods without snow, the 1D method shows good agreement with the 3D model but for periods with snow, the temperature in the soil is poorly predicted which will therefore give inaccurate prediction of heat losses. It has also been concluded by Zoras et al. [9] that 3D modeling of heat losses is the most appropriate method for calculation of the heat losses for foundations.

The present study is to investigate the heat losses from crawl space at different locations in Sweden by using the previously developed model by Risberg et al. [5]. The locations were chosen from the south to north of Sweden to get a variation in the number of snow days, snow depth and average outdoor temperature. For all the locations, the foundation ware placed in the same type of soil and the construction ware the same. In reality, the soil type and properties will depend on the location and the preparation of the soil before the construction, but this study will not focus on that specific. But to include some investigation of how this will affect the results, a sensitivity study was performed for the variables thermal conductivity and specific heat capacity of the soil. Also, three

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https://doi.org/10.1016/j.rineng.2020.100141
Received 21 February 2020; Received in revised form 22 April 2020; Accepted 7 May 2020

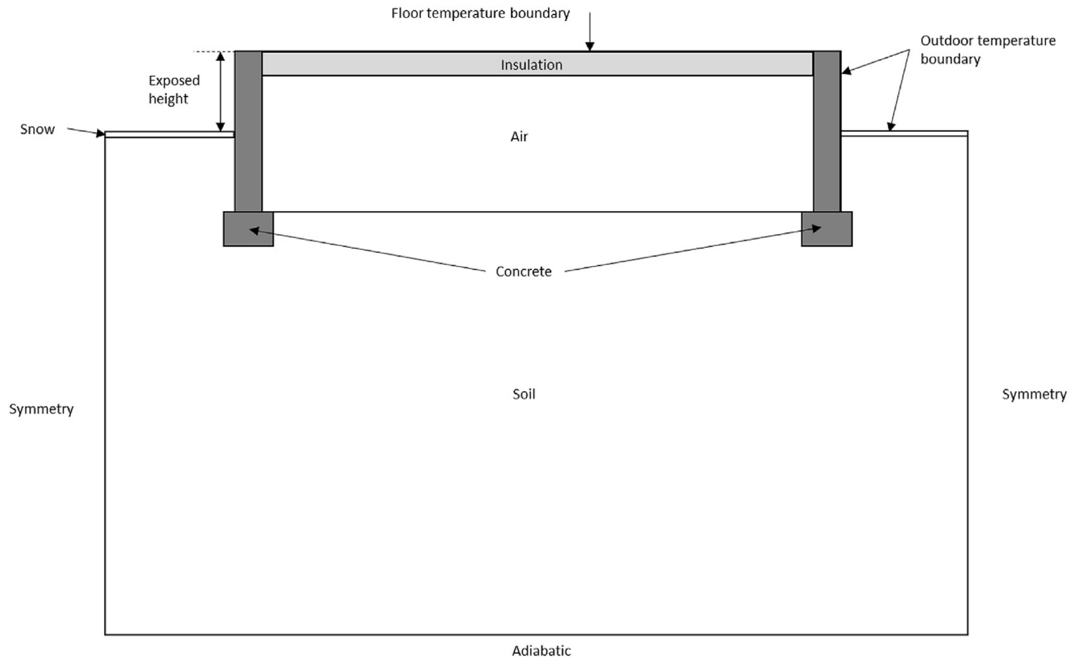


**Fig. 1.** Schematic overview of the model for the crawl space heat losses.

other essential parameters, outdoor air temperature, snow depth, snow days and thermal conductivity of the concrete beam was included in the sensitivity analysis. Especially it's of importance to get the knowledge of how outdoor temperature, snow depth and snow days will affect the heat losses since these parameters are often local and will change even if you are close to a metrological station where you can get these values.

To summarise this, the study is aimed to investigate the heat loss from a crawl space foundation at several different locations in Sweden together with performing a sensitivity analysis for the main parameters affecting the heat losses.

## 2. Method

### 2.1. Crawl space model

The model used is a 3D transient simulation model developed by Risberg et al. [5] in Ansys CFX 18.0. In Fig. 1 a schematic overview of the geometry of the model is presented. In the previous work, the model was validated against measurement for a crawl space located in Luleå a city in the north part of Sweden. The model considered both the soil freezing and the heat transfer through the snow. The model is assuming that the air in the crawl space is mixed and the radiation is calculated by the discrete transfer method [10]. The model was validated in the previous study for a crawl space located in Lulea and the maximum difference between measurement and model was 1.4 °C for a specific day during the year. The discretization error was also estimated previously to be small with an average deviation of 0.02 °C for the current mesh size of 1.01 million cells compared with a mesh size of 4.69 million cells. Soil properties are set according to previous work by Pericault et al. [11]. Where the soil dry density is 1600 $kg/m^3$, water content is 0.09 $m^3/m^3$, porosity is 0.4 $m^3/m^3$. To calculate the thermal conductivity of the soil Johansen's method was used [12]. The model was run for three years to get the initial conditions for the soil and foundation before the actual cases were run. The size of the crawl space was 11.26 m times 7.05 m and a height of 0.75 m. The exposed height of the foundation was 0.25 m. Outside the foundation, the simulation geometry includes 5 m in each direction and the soil included in the model is 10 m depth. The boundary conditions for daily average snow depth and the outdoor air temperature was set according to measurement data by SMHI (the Swedish Meteorological and Hydrological Institute) for the year 2018 [13]. To get the proper initial conditions the model was run 5 times with the initial conditions from the previous run before the results were taken at run 6. The convergence criteria for residuals for the energy equation the was set to $10^{-6}$ for the simulation and the time step used was 24h. The model is described in detail in Risberg et al. [5]. To be able to generalize the results also calculations for different sizes of the crawl space was performed. The crawl space length was varied from 5.63 m to 22.52 m while the other side was varied between at 3.525 m–14.1 m. The height was kept constant at 0.75 m. From the results a polynomial equation was created that can be used to recalculate the average heat flux for different size of crawl space.

### 2.2. Locations and climate data

The six different locations investigated are presented in Table 1 and Fig. 2. The location was chosen to get a wide variation in average temperature, snow days and average snow depth together and are specific location ware SMHI has measurements of snow depth and temperature available. The location was also chosen to get a spread over Sweden from south to north. The average temperature for the year has a difference from 0.18 to 10.2 °C. The number of snow days varied between 14 and 192 days and the average snow depth between 0.04 m and 0.80 m.

### 2.3. Response surface modeling for sensitivity analysis

Outdoor air temperature and the number of snow days are parameters that determine the heat flux from the foundation. Also, the properties for the soil around the house, concrete properties and the snow depth are other parameters that will determine the heat flux from the building. So it is necessary to understand how sensitive all these are for the foundation heat losses. Therefore, the considered parameter in this study is snow depth, number of snow days, specific heat capacity and thermal conductivity for the soil, thermal conductivity for the concrete and outside air temperature. All the considered parameter was varied by multiplying by a factor 0.5 to 1.5 (±50%) except the air temperature that was varied ±5 °C and the number of snow days that was varied ±20 days. The original values used in the sensitivity is for the Gävle location since its values are closest to the average values for all the considered locations.


**Fig. 2.** Locations studied in Sweden for the crawl space heat losses.

**Table 1**
Locations and data for the crawl space heat losses.

| | Falsterbo | Linköping | Gävle | Umeå | Luleå | Kiruna |
|---|---|---|---|---|---|---|
| Latitude | 55.4 | 58.4 | 60.7 | 63.8 | 65.6 | 67.9 |
| Longitude | 12.8 | 15.5 | 17.1 | 20.2 | 22.2 | 20.2 |
| Average Temperature [°C] | 10.2 | 8.08 | 6.56 | 4.34 | 2.97 | 0.18 |
| Snow days | 14 | 59 | 129 | 138 | 147 | 192 |
| Average snow depth [m] | 0.04 | 0.08 | 0.29 | 0.375 | 0.80 | 0.55 |

For the sensitivity analysis, response surface methodology [14] was used to build a second-order polynomial model according to equation (1). The variables were varied according to central composite design, which gives in total 45 different cases which are used to create the response surface model. The equation for the relationship is then obtained in the following form for both average, minimum and maximum heat flux:

$$\dot{q} = \beta_0 + \sum_{i=1}^{6} \beta_i X_i + \sum_{i=1}^{6} \beta_{ii} X_i^2 + \sum_{1 \le i \le j}^{6} \beta_{ij} X_i X_j \quad (1)$$

where X is the variables that are varied $\beta$ are the response surface model coefficients. The following indices are used with the corresponding unit: 1. Air Temp [±°C], 2. Thermal conductivity for the concrete [0.5–1.5] 3. Thermal conductivity for the soil [0.5–1.5], 4. Specific heat capacity for the soil [0.5–1.5], 5. Snow depth [0.5–1.5], 6. The number of snow days [±days]. For all variables except air temp and snow days, the variables were multiplied by a factor of 0.5–1.5 which corresponds to percent variations of ±50%.

## 3. Results and discussion

### 3.1. Heat flux at different locations

Fig. 3 shows the Heat Fluxes over the year for all the considered locations and Table 2 summarizes min, max, and average heat fluxes. The minimum heat flux 0.43 W/m$^2$ was in Falsterbo during the summer which is around 46% lower than the average minimum heat flux. In Kiruna the minimum heat flux was 1.38 W/m$^2$ which is 220% higher than in Falsterbo. The maximum heat flux was in Kiruna 4.43 W/m$^2$ during the winter which is 20% higher than the average maximum heat flux. The maximum heat flux during a year was lowest in Falsterbo with a value of 1.76 W/m$^2$. The average heat flux varied between 1.73 and 3.07 W/m$^2$ where the lowest was in Falsterbo and highest in Kiruna. The difference between these is 50% higher average heat flux for Kiruna. The average heat flux considering all the locations over the year is 2.36 W/m$^2$ which gives that Kiruna is 30% above average and Falsterbo 25% below the average. The variation over the year is similar for all the locations where the difference between max and min over the year is between 2.75 and 3.05 W/m$^2$ for the different locations.

To recalculate the average heat flux $\dot{q}_{diff\_size}$ to other sizes of crawl space, the following polynomial equation was created from the modeling results.

$$\dot{q}_{diff\_size} = \dot{q}_{ave}\left(1.10574192 - 0.006243488\left(\frac{l_1}{11.26}\right) - 0.031051995\left(\frac{l_2}{7.05}\right) - -0.029226160\left(\frac{l_1}{11.26}\right)\left(\frac{l_2}{7.05}\right)\right) \quad (2)$$

where $l_1$ and $l_2$ are the two different lengths of the crawl space and $\dot{q}_{ave}$ is the average heat flux for a specific location. Based on this, it can be calculated that average heat flux decreased by 12.5% when the area of the house is quadrupled.

### 3.2. Response surface model and sensitivity analysis

The analysis from response surface modeling gives the following equations to predict the average, maximum and minimum heat flux:

$$\begin{aligned}\dot{q}_{ave} = {} & 2,6046440 - 0,3972510X_1 + 0,0178576X_2 \\ & + 0,0270083X_3 - 0,1213957X_4 - 0,0127195X_5 \\ & + 0,0068967X_6 - 0,0028780X_1X_1 - 0,0020750X_2X_2 \\ & - 0,0033075X_3X_3 + 0,0107080X_4X_4 + 0,0032335X_6X_6 \\ & - 0,0048558X_1X_2 - 0,0078927X_1X_3 + 0,0096959X_1X_4 \\ & + 0,0016604X_1X_5 + 0,0024801X_1X_6 - 0,0020257X_2X_3 \\ & + 0,0023513X_2X_4 - 0,0015487X_4X_6 \end{aligned} \quad (3)$$

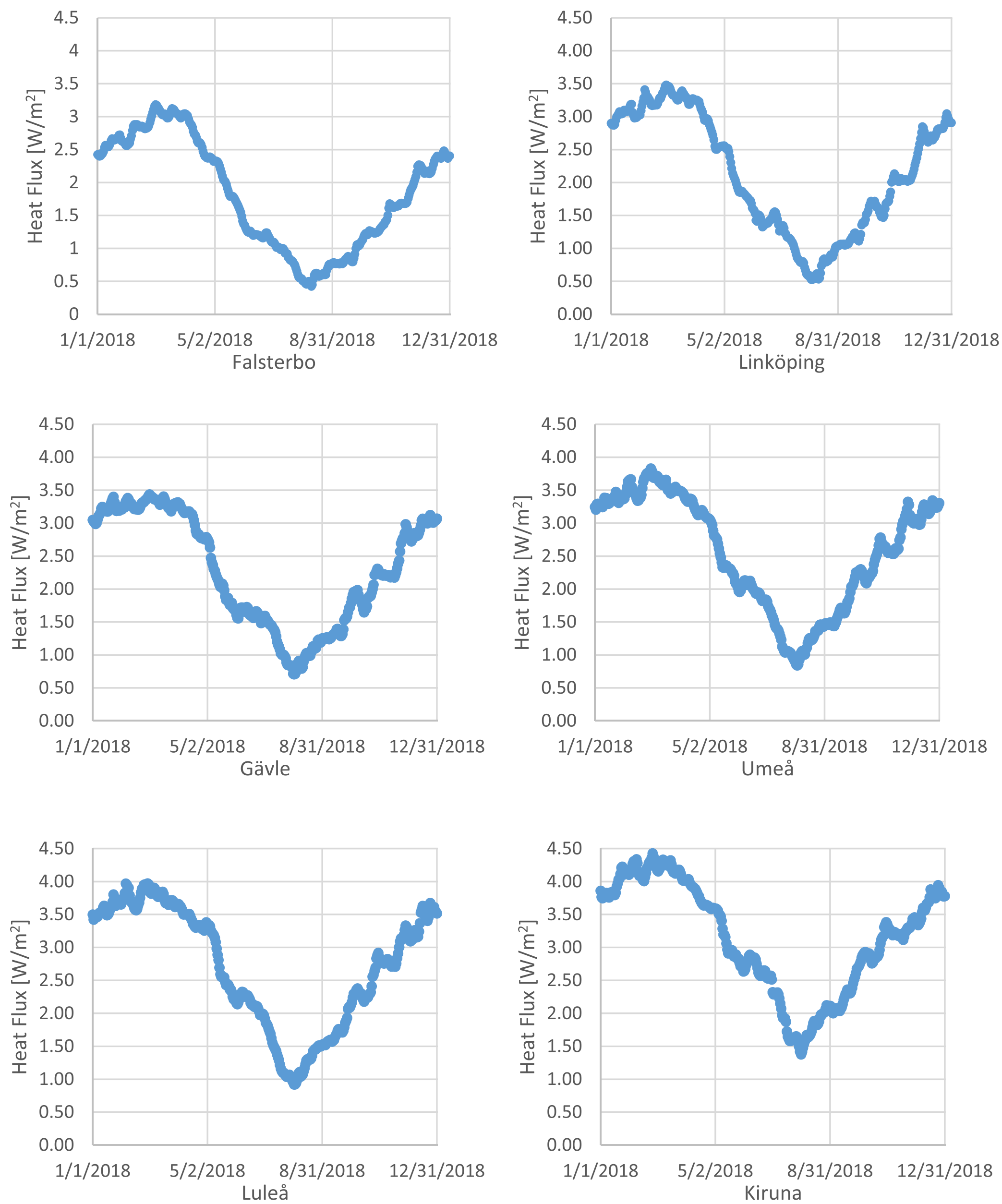


**Fig. 3.** Heat Flux over the year for the different locations.

**Table 2**
Min, Max, and Average Heat Flux at different locations.

| | Falsterbo | Linköping | Gävle | Umeå | Luleå | Kiruna | Average |
|---|---|---|---|---|---|---|---|
| Max Heat Flux (W/m$^2$) | 3.18 | 3.48 | 3.44 | 3.83 | 3.97 | 4.43 | 3.72 |
| Min Heat Flux (W/m$^2$) | 0.43 | 0.53 | 0.71 | 0.84 | 0.92 | 1.38 | 0.80 |
| Average Heat Flux (W/m$^2$) | 1.76 | 2.04 | 2.19 | 2.47 | 2.62 | 3.07 | 2.36 |

$$\begin{aligned}\dot{q}_{max} = {} & 1,5311404586703 + 0,0670282X_1 + 0,0101438X_2 \\ & - 0,00075060956X_3 - 0,0439680X_4 - 0,0077131X_5 + 0,0027248X_6 \\ & - 0,0025967X_1X_1 - 0,0011923X_2X_2 + 0,0015376X_4X_4 \\ & + 0,0032335X_6X_6 - 0,0009788X_1X_3 - 0,0014358X_1X_4 \\ & + 0,0008114X_1X_6 - 0,0008558X_2X_3 + 0,0008790X_2X_4 \\ & - 0,0008903X_3X_4\end{aligned} \tag{4}$$

$$\begin{aligned}\dot{q}_{min} = {} & 7,5170257 - 3,6676574X_1 - 0,2791200X_2 + 0,3079960X_3 \\ & + 0,0984928X_4 - 0,0378696X_5 + 0,0213087X_6 + 0,0178201X_2X_2 \\ & - 0,0240685X_3X_3 - 0,0248543X_4X_4 + 0,0066480X_6X_6 \\ & - 0,0383811X_1X_2 - 0,0740980X_1X_3 + 0,0659856X_1X_4 \\ & + 0,0192602X_2X_4 + 0,0475009X_3X_4\end{aligned} \tag{5}$$

The description of the indices in equations (3)–(5) is presented in section 2.3. Overall it can be seen that the linear and quadratic term are

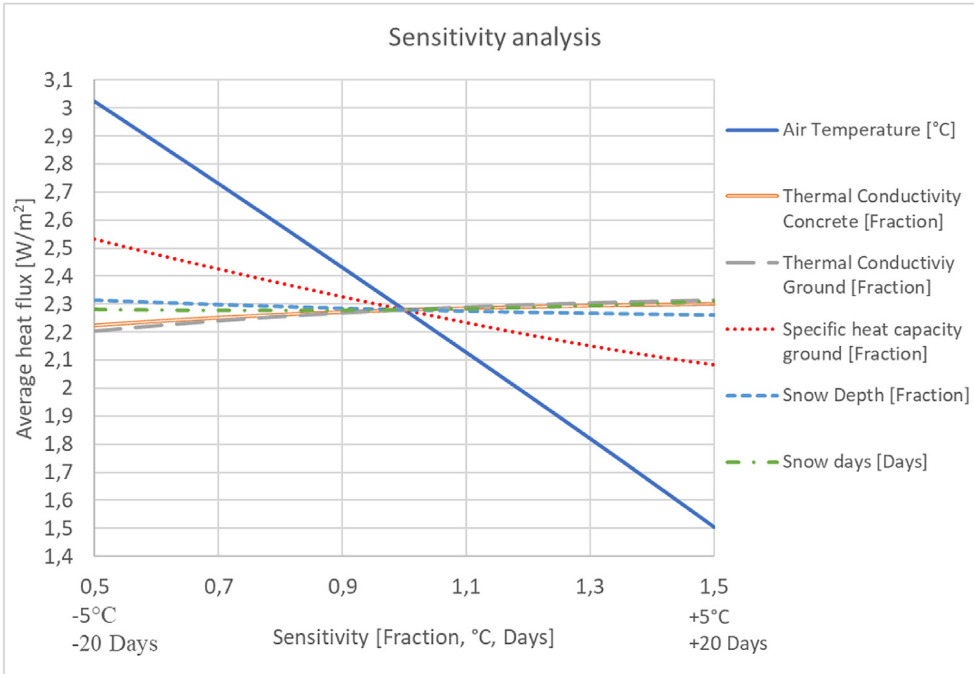


**Fig. 4.** Sensitivity analysis for average heat flux over the year.

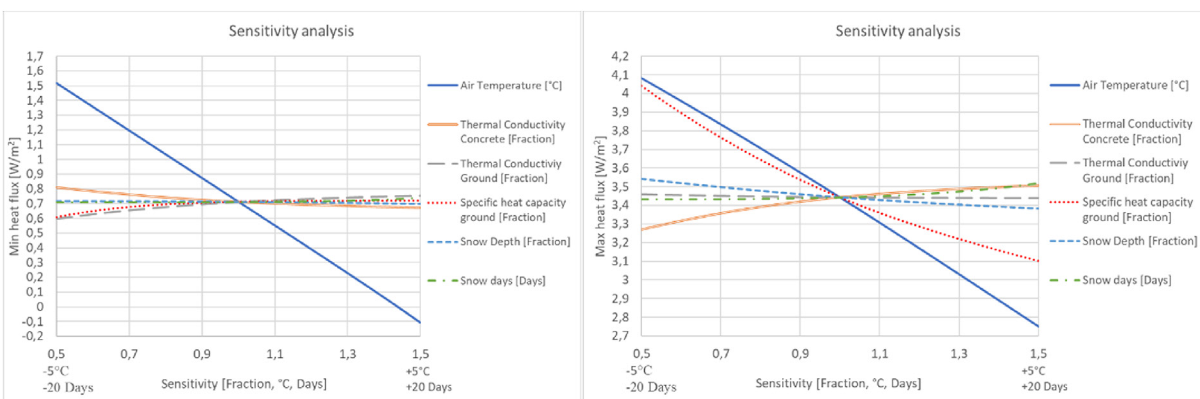


**Fig. 5.** Sensitivity analysis for minimum and maximum heat flux.

most important and the interaction terms only have a minor impact on the average, maximum and minimum heat flux.

The results from the sensitivity analysis are presented in Fig. 4. The air temp changes the average heat flux from the ground by 0.15 W/m$^2$ per degree temperature change. It can also be seen that the specific heat capacity of the soil is an important parameter and the average heat flux is decreased by 8.6% when the specific heat capacity is increased by 50%. This indicates that it's of importance to consider the soil type around the foundation for calculation of heat flux from foundations which is in line with previous results by Khaled et al. [15]. This means that it would be preferable to have soil with a higher specific heat capacity near the foundation. For the snow depth, the change is only 2.3% which will be insignificant when you consider the heat losses for a whole building. The variations in the number of snow days also have an insignificant impact on the average heat losses for the considered locations. The results indicate that the most crucial parameter is the air temperature which also is the parameter that is measured at most locations in Sweden by SMHI. The snow depth is determined at fewer locations but since this parameter is less significant for the results, it will probably be satisfactory to use a location that is not so close to the specific place. The current snow modeling in the numerical model is not so comprehensive, so it could be possible to improve it by using validated linear models to predict the correct snow surface temperature [16]. But it is not necessary for the current application since the results are not significantly affected by the number of snow days and snow depth. For thermal conductivity of both the ground and the concrete its minimal variations in the average heat losses with an increase of around 1% when the thermal conductivity was increased by 50%. Variations in thermal conductivity will have a more significant effect if you decrease it significantly by adding insulation material to the crawl space foundation. In previous studies by Risberg et al. [5] the heat losses were decreased by 40% when the crawl was insulated.

In Fig. 5 the sensitivity for minimum and maximum heat flux are presented. For the minimum, it can be seen that the air temperature is the most crucial parameter for the considered variations and variation of the other parameters has minimal impact on the minimum heat loss. The parameters connected to snow will have no impact on this since it's no snow during the period when the heat losses are at a minimum. One interesting part that can be seen is if the outdoor air temperature is 5 °C warmer it will be days during the year when there are no or positive heat flux through the foundation. For the maximum heat losses, it can be seen that thermal properties both for the ground and concrete are of importance. The most important parameter after air temperature is the specific heat capacity for the soil. The maximum heat flux was changing 30% when the specific heat capacity was varied ±50%. The reason for this is that the soil in the ground will work as a thermal buffer when the temperature decrease at the coldest days and therefore when the specific heat capacity decreases will give a lower buffer capacity and therefore the heat losses increase. The number of snow days will have no effect on the maximum heat losses since during the coldest days it will be snow anyway. The maximum heat flux will variate 5% when the snow depth is varied ±50%. From the results, it can be seen that if the thermal conductivity for the concrete is variated ±50% the maximum heat loss change almost 7%.

## 4. Conclusions

The current work, study how the heat losses through the crawl space foundation variate at different locations in Sweden. The average heat flux from the foundation varied between 1.76 and 3.07 W/m̈2 which corresponds to 75% higher heat flux for the most northern location compared to the most southern location. For the maximum heat flux, the difference is only 39.3%, while the minimum heat flux difference is 321% higher between the most north and most south locations studied. The average heat flux decreased by 12.5% when the area of the house is quadrupled.

The most crucial input variable for prediction of the average heat flux from the crawl space during the year is the air temperature. Each degree increase in the outdoor air temperature gives a 0.15 $W/m^2$ decrease in average heat flux. The snow depth and the number of snow days are of less importance and give less than a 2.3% decrease for a variation of ±20 days and ±50%.

From the sensitivity analysis, it can be concluded that the specific soil type needs to be considered especially for the specific heat capacity which gives that the heat losses are decreased by 8.6% with an increased heat capacity of 50%.

To predict the maximum heat flux, it's of importance to have a correct specific heat capacity of the soil since the maximum heat flux variate between 4.04 and 3.1 $W/m^2$ for a ±50% variation in the specific heat.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRediT authorship contribution statement

**Mikael Risberg:** Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Daniel Risberg:** Conceptualization, Methodology, Investigation.

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