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Conduction Shape Factors for Thermally Active Retaining Walls

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The walls of a structure below the ground level can also be utilised for exchanging heat energy from shallow depths, thereby accessing shallow geothermal energy for indoor heating and cooling, in addition to their primary role of resisting structural loads. This thermal activation of walls is achieved by installing the heat exchanger pipes at the time of construction of the wall, and these are commonly termed energy walls. These energy walls are used for underground parking spaces, basements and underground stations. For the efficient thermal design of these structures, simple analytical solutions are required to characterise their heat transfer. In this extended abstract, we compare the temperature change computed across energy walls for different calculation methods, including steady-state shape factors and numerical approaches.

Energy walls follow a repetitive pipe arrangement which can be installed horizontally and vertically; however, vertical arrangements are more common due to ease of installation [1]. This leads to a simplified repetitive geometry shown in Figure 1(a), where the pipe is placed closest to the ground, whether we assume a constant temperature, and the other side of the wall is assumed insulated as per [2]. These pipe arrangements within walls can be compared with pipes buried in the ground, e.g. for district heating or other applications (Figure 1(b), (c)). These buried pipes, mostly large-diameter pipes, carry fluids at higher temperatures for large distances, making understanding heat transfer and heat losses extremely important. Therefore, heat conduction in this field has been explored in more detail with the result that shape factors for steady-state heat transfer are readily available [3].

Conduction shape factors (S) are easy to apply and can be used to assess the temperature difference between the heat transfer fluid and the back of the energy wall (T_C) due to the thermal resistance (R) of the wall concrete via equation (2). There are two shape factors which are tested in the work; S_{B1}=single buried pipe (Figure 1(c), equation (3) [4] and S_{B2}=equally spaced buried pipes (Figure 1(b), equation (4)) [4], and compared to steady state shape factor (S_N) calculated numerically. The reason for testing them both is because the pipes in the wall are of minimal diameter, 20mm to 28mm, compared with wall dimensions of 0.4m to 1.2m or pipe spacing of 0.3m to 0.8m. T_C calculated from the two shape factors is compared with results from two numerical models for a range of geometries. At first, the geometry shown in Figure 1(a) is solved for the steady state, after which a ground length is added to it, the transient state is analysed, and T_C is calculated via equation (1).

$$T_C = T_P - T_W \quad \ldots(1) \qquad T_C = QR = {}^{Q}\!/_{KS} \quad \ldots(2)$$

$$S_{B1} = {}^{2\pi}\!/_{\ln(4c'D)} \quad \ldots(3) \qquad S_{B2} = {}^{2\pi}\!\Big/_{\ln\left(\frac{2s}{\pi D} sinh\left(\frac{2\pi c'}{s}\right)\right)} \quad \ldots(4)$$

where Q (W/m) is the heat flux, S is the shape factor, s is spacing between the consecutive pipes (m), D is the pipe diameter(m), and K is the thermal conductivity of concrete (W/mK). T_P and T_W are the temperature changes at the temperature changes The results are presented in Figure 1 for varying pipe spacing and wall thicknesses: wall thickness W=0.6m, 0.8m, 1m, and 1.2m; 3 pipe spacing s=0.3m, 0.5m, and 0.8m. In all cases, the pipes are 25mm in diameter and offset 75mm from the back of the wall. Constant heat flux per unit area, q=12*s W/m^{2,} is applied for 1 year in the case of the transient analysis.

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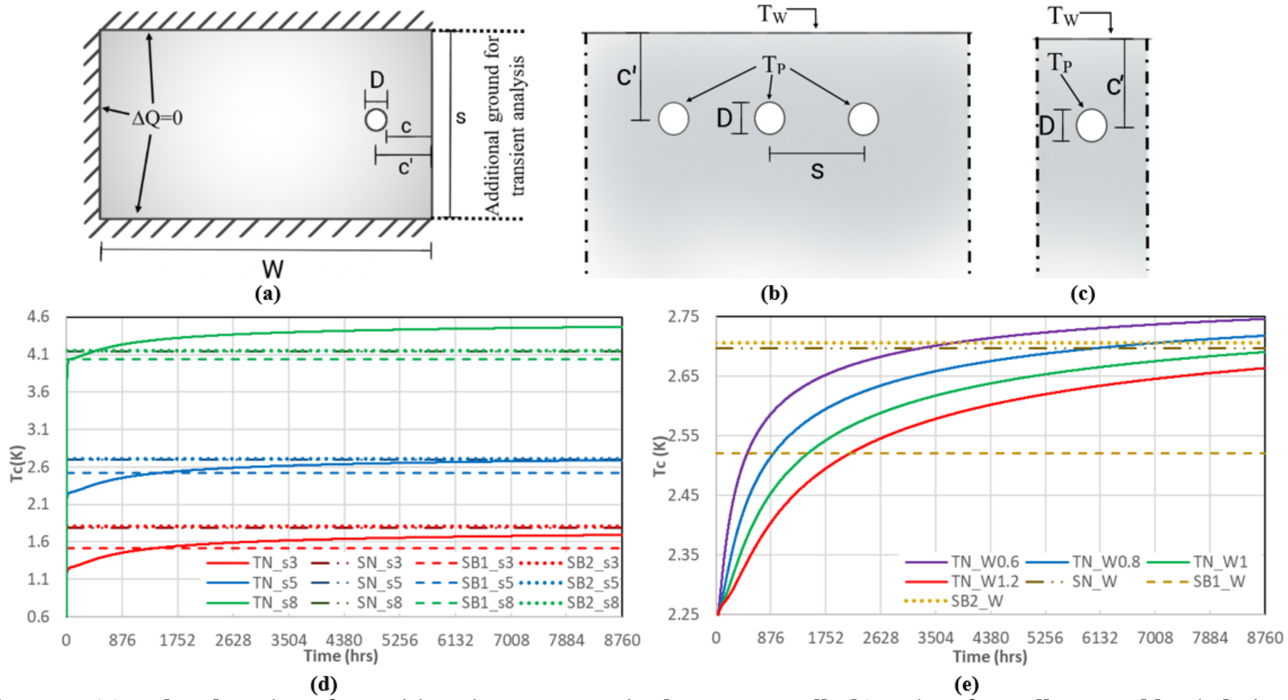

Figure 1: (a) Isolated section of repetitive pipe geometry in the energy wall, (b) series of equally spaced buried pipe, and (c) single burried pipe; and the comparision of the temeprature changes for numrtrical transient solution (TN) and steady state numerical solution(SN) and anlytical solution (using shape factors SB1 and SB2) for (d) vaying pipe spacing (S) and walls 1m in thickness and (e) varying wall thickness (W) with fixed pipe spacing of 0.5m (All values in m for legends).

The buried pipes in the ground form a good analogy with the embedded pipes of energy walls for the calculation of temperature changes due to thermal resistivity. Compared to the results from the steady state numerical analysis, T_{SN}, T_C from the equally spaced pipes model has an accuracy between 99.1-99.7%, while that from the single buried pipe model has an accuracy between 81.5-97.3%. This shows that for shape factors in energy walls, pipe spacing is essential, but wall thickness does not play such a significant role in the general range. Therefore, in Figure 1(e), the steady-state responses from different thicknesses overlaps. However, when the effect of the ground behind the wall is included for the transient simulation, the results at a pseudo-steady state are not identical and depend on the pipe spacing and wall thickness. Models with smaller wall thicknesses reach a steady-state-like condition quicker, whereas models with higher wall thicknesses may need almost a year to reach a steady state. Through this analysis, it can be concluded that the shape factors used for the buried pipe can also be used for the energy walls. Of the two studied shape factors, the formulation S_{B2} shows values very similar to the numerically calculated values.

Contributor statement

Aakash Gupta: Conceptualization, Methodology, Formal analysis, Visualisation, Investigation, Methodology, Writing - original draft, review & editing. Fleur Loveridge: Conceptualisation, Visualisation, Writing - review & editing, Supervision, Funding acquisition, Resources. Ida Shafagh: Conceptualization, Visualization, Writing - review & editing, Supervision, Funding acquisition, Resources. Simon Rees: Writing - review & editing, Supervision, Funding acquisition, Resources.

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