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# Assemblies of heat pumps served by a single underground heat exchanger



HEAT and M

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#### 1. Introduction

There is an increasing interest in the future of urban design as a growing vasculature with high-density transport ranging from building energy design (heating, air conditioning) to power distribution, transportation, and communications. The future points toward thicker urban settlements, and this means even higher densities of transport.

One important class of high-density designs are buildings connected thermally to the ground [1–25]. The connection is effected by heat pumps that deposit or extract heat through fluid loops buried in the ground. As neighborhoods become denser, and as the inhabited space expands vertically (above and below ground), the land area with which the buildings are coupled becomes essential. This is why in Ref. [26] we proposed the idea of coupling two heat pumps in a single underground heat exchanger. We showed how the heat exchanger interacts with the soil volume, and that heat pumps of different sizes may operate better when they share a single underground loop. We also reported the effect of the pressure losses and overall performance of the design.

In this paper we consider the design of assemblies of multiple heat pumps that operate while connected to a straight single loop underground heat exchanger (Fig. 1). The degrees of freedom of the

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#### ABSTRACT

In this paper we document the relationship between complex flow architecture and global performance for assemblies of heat pumps coupled thermally with the ground through a single U-shaped loop with circulating fluid. The assemblies vary according to heat pump numbers, sizes and locations along the loop. They are classified in a systematic way, and their performance is documented in three classes of designs: assemblies of heat pumps of the same size, heat pumps distributed equidistantly, and large numbers of heat pumps distributed almost continuously on a long loop. The work is based on numerical simulations, and on an analysis that holds in the limit of heat pumps distributed continuously. The relationship between flow architecture and global performance (heat transfer density) serves as guide for the energy design of high-density urban settlements in the future.

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design are the sizes of the heat pumps and the positions of their connections along the loop.

We first consider assemblies with equal-size heat pumps and with variable connecting locations along the loop. We then position the heat pumps equidistantly along the loop and vary their sizes. The number of heat pumps varies from 1 to 4. Finally, we consider assemblies in the limit of large numbers of heat pumps distributed almost continuously on a long loop. In accord with constructal design [27,28] we seek the trends in how the global performance of the design depends on the flow architecture of the assembly.

#### 2. Model

Consider a group of buildings that use heat pumps to extract heat from the ground by sharing the same underground heat exchanger (Fig. 1). The limiting case is a single heat pump operating with its own heat exchanger (configuration 1A1 in Table 1). More complex assemblies consist of two or more heat pumps distributed along longer heat exchangers.

We model the buried heat exchanger as a hairpin-shaped pipe. Heat pumps are connected to the loop on one leg for intake, and on the opposite location on the other leg to retrieve the working fluid. Therefore, in the intake leg the mass flow rate increases along the direction from the first to the n<sup>th</sup> heat pump, as more fluid is added in each. The mass flow rate decreases after the stream passes the U-turn (Fig. 2).

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$f_j$ mass flow rate ratio defined as $f_j = m_{HPJ}/\dot{m}_{HP1}$ $T_m$ mean temperature of the flow in the pipe, K $H$ height of the soil portion, m $K$ $mean temperature of the flow in the pipe, Kk_fthermal conductivity of soil, W/m KKmean temperature of the flow at the heat pump j intk_seffective thermal conductivity of soil, W/m KKKL_{en}equal distance between heat pumps, mKKL_{en}equal distance between heat pumps, mKKL_{nr}length of the soil position and one of the legs associatedto heat pump j, mKVvolume of soil in which the pipes are buried, m3L_{nr}length of the soil portion and one of the legs of the entirepiping assembly, mKVvolume, mL_{act}saturation length for enthalpy gain, mKVvolume, ml_jthe position along the x-axis at which the heat pump j,sconnected to the pipe, m\phifluid density, kg/m3m_{HPj}mass flow rate in the pipe after the last node n, kg/s\rhofluid density, kg/m3P_{PD}Peclet number at the first stretch between junction 1and 2, as Eq. (11')\tilde{\nabla}^2dimensionless total enthalpy gain of heat pump jtake\tilde{Q}_{HPnT}dimensionless total enthalpy gain of all heat pumps ofn-assembly\tilde{\nabla}^2dimensionless longitudinal coordinate\tilde{V}Repo Reynolds number with respect to the pipe diameterSspacing between the two straight pipes, mt\tilde{L}_{att}\tilde{L}_{att}<$	CP	specific heat of the fluid, J/kg K	T <sub>inlet</sub>	temperature at which heat pumps connects to the pipe,
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the saturation lengthSuperscript $T_{\infty}$ far field soil temperature, K(~)	$\tilde{t}_{sat}$		C	.,
$I_{\infty}$ far field soll temperature, K				
	$T_{\infty}$	far field soil temperature, K	(~)	dimensionless
	$T_f$	temperature field in the pipe fluid, K		
	5			

All heat pumps feed the loop with a mass flow rate  $\dot{m}_{\rm HPj}$  at the same temperature,  $T_{inlet}$ , and retrieve the fluid in local mean junction temperature,  $T_{m\cdot out\cdot j}$ , which resulted from the heat transfer from the soil to the fluid (Fig. 2).

The heat exchanger interacts thermally with a volume of soil shaped as parallelepiped (Fig. 3). The side boundaries of the volume are modeled as surfaces at uniform temperature,  $T_{\infty}$ . We

consider the volume as homogenous solid with constant, uniform and isotropic properties. The U-shaped pipe with diameter *D* has sufficiently thin wall and high enough thermal conductivity such that its wall thermal resistance is negligible.

The first heat pump (HP1) is connected at x = 0 (Fig. 3). The other heat pumps are located at  $x = l_j$ . The two legs of the U are laid in the horizontal plane x-y with centers at  $y = \pm S/2$ . The mass flow

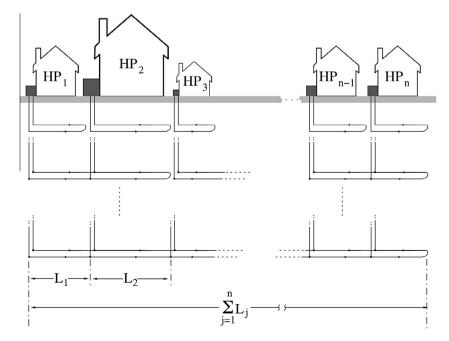


Fig. 1. Groups of buildings (heat pumps) that interact thermally with the ground: from isolated heat exchangers to assemblies of heat pumps served by a single loop.

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