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The influence of environmental and geometrical factors on air-ground tube heat exchanger energy efficiency

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ABSTRACT

More and more efficient solutions of thermal insulation of buildings result in an increasing role of ventilation in the energy balance of buildings. This leads to a necessity for seeking unconventional heat sources, as well as development of the exhaust air heat recovery methods. The use of heat accumulating potential of the ground perfectly fits into this trend, allowing natural pre-heating and pre-cooling of the inlet air. There appears to be very limited research and published data on their thermal performance in Poland. This paper introduces a developed method of air-ground heat exchanger (AGHX) performance evaluation together with its validation and research results of conducted simulation. The AGHX model (based on a quasi 3D finite elements method) allows analysis of energy performance dependence on a wide range of parameters including AGHX geometrical configuration, mode of operation and environmental factors. The simulation results indicate that the analyzed parameters in various degrees affect the thermal efficiency of AGHX; various is also the nature of their impact. For some of them it is possible to set a value to maximize heat or cold yield (pipe diameter and placement depth, number of parallel pipes, bypass system, soil thermo-physical parameters, ground area shading and ground surface cover). In other cases, the influence of parameters has an asymptotic nature for which the maximum heating or cooling efficiency is achieved for parameter values tending to infinity (pipe length and distance between parallel pipes).

1. Introduction

In Polish climatic conditions, air-soil heat exchangers allow up to about 20 K of air temperature increase in winter, keeping the outlet air temperature above 0 °C. Similarly, in summer ventilation air can be cooled down by about 10 K, keeping the ventilation air temperature below 25 °C [15]. As a result, both the energy demand and capacity for ventilation air preparation can be significantly reduced, both for winter and summer. Moreover, there is no frost risk in installations equipped with heat recovery systems.

There are two major design solutions that enable heat accumulating potential of the ground utilization; these are tube and gravel heat exchangers. As the tube heat exchangers have hermetic construction, they are much safer in exploitation due to low microbiological risk.

Investment and operation cost rationalization require a proper methodology of air-ground tube heat exchanger design and energy efficiency estimation. Although the use of AGHX for pre-heating and pre-cooling of ventilation air is gaining recognition as a low carbon emission technology, there is very limited research and published data on their energy performance in Poland. Various sizes and shapes of building plots, their location, different types of soil and location of buildings on the plot affect the size and configuration of the heat exchanger. The number of parameters influencing AGHX energy performance makes simplified methods of its energy performance evaluation inadequate. Lack of adequate design information might reduce the interest in application of this technology in buildings.

2. AGHX modeling

AGHX energy performance analysis requires taking into account the specific conditions of a building plot. There is a number of analytical and numerical models for predicting the outlet air temperature [1]. These models differ in the level of accuracy, complexity and assumptions. Steady state heat transfer analysis, such as the method proposed in Ref. [14], is inappropriate for AGHX calculation, as it is a transient system where heat transfer between air and soil influences soil temperature profile around the pipe. Also numerical models based on three-dimensional heat and mass transfer (like the one proposed in Ref. [8]) may be insufficient for calculations due to AGHX geometry

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