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The effect of wind speed on the economical optimum insulation thickness for HVAC duct applications

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ABSTRACT

This study deals with the investigation into optimum insulation thickness of HVAC ducts and the effect of wind speed on it for the city of Uşak, Turkey. Optimum insulation thickness, energy savings over a lifetime of 10 years and payback periods are determined for the four different energy types as coal, fuel–oil, LPG and natural gas and two different insulation materials as fiberglass and rockwool. By using the P_1–P_2 method, the value of the amount of the net energy savings is calculated. The results indicate that optimum insulation thicknesses vary between 12.85 and 23.91 cm, energy savings 79.36 and 98.45%, and payback periods 0.0053 and 0.0925 years depending on the type of fuel for fiberglass, whereas, optimum insulation thicknesses vary between 11.87 and 22.21 cm, energy savings 76.63 and 98.26%, and payback periods 0.0061 and 0.1115 years depending on the type of fuel for rockwool. Moreover, 7 ms^{-1} wind speed for LPG is highest in energy saving but 0.2 ms^{-1} wind speed for natural gas is lowest in energy saving. Finally, the application of insulation in high wind speeds is more advantageous.

Contents

1. Introduction

HVAC stands for “heating, ventilation and air conditioning,” three functions often combined into one system in today's modern homes and buildings. Among building energy services, HVAC systems are the most energy consuming devices, accounting for about 10–20% of final energy use in developed countries [1].

Only heating systems, prevalent in cold climates, have such source of heat generation as natural gas, fuel oil, liquid petrol gas or coal and typically use air to deliver the heat to the conditioned space and the hot air flows through a series of tubes – called ducts – to be distributed to all the rooms of building's occupants. Typical duct locations of HVAC system are outdoor environment, attics, crawlspaces and garages. Putting ducts in these non-conditioned areas increases the potential for energy losses from the duct system because the duct are exposed to a harsher environment and energy loss from the ducts is outside the conditioned envelope of building. These losses contribute to large energy bills for home owner and to large peak demands for utilities. Therefore, thermal insulation of the HVAC ducts is one of the most valuable tools to prevent these heat losses and also the thermal insulation prevents condensation on the duct surface.

Determining both the type of thermal insulation material and the economic thickness of the material used in the HVAC's duct are the main subjects of many engineering investigations. The concept of

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Nomenclature

A	surface area of duct (m^2)
C	price ($ kg^{-1}, $ m^{-3})
d	inflation rate (%)
D	diameter (mm)
$\dot{E}$	energy rate (J m^{-1} $year^{-1}$)
ES	energy saving ($ m^{-1})
h	convection transfer coefficient (W m^{-2} K^{-1})
HDD	heating degree-days (°C-days)
H_u	lower heating value of the fuel (J kg^{-1}, J m^{-3})
i	interest rate (%)
k	the heat transfer coefficient (W m^{-1} K^{-1})
L	length (m)
$LCCA$	life cycle cost analysis
LPG	liquid petrol gas
m	fuel consumption (kg m^{-1} $year^{-1}$, m^3 m^{-1} $year^{-1}$)
N	lifetime (years)
Pr	Prandtl number (-)
PP	payback period (years)
$\dot{Q}$	heat loss (J m^{-1} $year^{-1}$)
R	thermal resistance (K W^{-1})
Re	Reynolds number (-)
t	wall thickness (mm)
T	temperature (K)
U	overall heat transfer coefficient (W m^{-1} K^{-1})
V	speed (m s^{-1}), volume (m^3)
x	optimum insulation thickness (cm)
η	efficiency

Subscripts

a	annual
f	total fuel
fg	fiberglass
F	fuel
i	inside
ins	insulation
o	outside
opt	optimum
rw	rockwool
s	heating system
t	total
$un\text{-}ins$	un-insulation
w	wind

economic thermal insulation thickness considers the initial cost of the insulation system plus the ongoing value of energy savings over the expected service lifetime of the insulation. To minimize the energy and insulation costs in addition to reducing the heat loss to the surroundings, the thickness of the insulation material needs to be optimized. The economic insulation thickness for a pipe is a function of a large number of parameters, such as pipe size, cost, conductivities of the pipe and the insulation material, operating and ambient temperatures, heat transfer coefficients at the inside and outside of the pipe, economic parameters and annual operation hours [2].

In most studies, the optimum insulation thickness calculations in the pipe were performed based mainly on the heating load and other parameters such as the costs of the insulation material and energy, efficiencies of the heating system, the lifetime, and the current inflation and discount rates. For that reason, the annual heating energy requirement of a building was the main inputs required to analyze the optimum insulation thickness. Most studies estimated the heating energy requirement by the degree-time concept (degree-day, DD, or degree-hour, DH), which is one of the simplest methods applied under static conditions. Zaki ve Al-Turki studied economic analysis of thermal insulation for a system of pipelines, from the oil industry, insulated by different materials composite layers. The analysis was based on an explicit nonlinear cost function that includes the annual energy losses and the insulation initial costs. In the analysis, rockwool and calcium silicate as insulation materials and a system of pipelines (0.1–0.273 m nominal size) with flow of superheated steam, furfural, crude oil, and 300-distillate was employed and h_o was assumed constant, 10 W m^{-2} K^{-1} [3]. Li and Chow analyzed methods for protecting water pipes, in cold regions against freezing, by thermal insulation material and heating cable. They applied a thermoeconomic optimization analysis with a simple algebraic formula derived for estimating the optimum insulation thickness for tubes of different diameters varying from 0.02 m to 0.2 m. The optimization was based on a life-cycle cost analysis. They investigated the effects of outdoor air conditions and design parameters on the optimum thickness. For the same outside-air temperature, the optimum insulation-thickness would become larger for lower design insulation envelope outside-temperature. It was also found that the optimum insulation thickness was inversely proportional to the thermal conductivity and cost of the insulating material. Predicted results of this study would provide useful reference data when considering design, practical operation or maintenance [4]. Öztürk et al. presented four different thermo-economic techniques for optimum design of hot water piping systems. They were as follows: the first one was a sequential optimization of pipe diameter based on minimization of total cost without considering heat losses and then of insulation thickness based on minimization of cost of insulation and heat losses. The second was simultaneous optimization of pipe diameter and insulation thickness based on the first law of thermodynamics and cost. The third was simultaneous determination of pipe diameter and insulation thickness based on maximization of exergy efficiency without considering cost. Finally, the fourth was simultaneous determination of pipe diameter and insulation thickness based on maximization of exergy efficiency and cost minimization. A case study was carried out for a hot water pipe segment, and the differences and merits of each method were discussed. Important parameters such as annual operation time, depreciation period, interest rate, fuel and electricity prices, and the thermo-physical parameters were assumed to be the same and constant for all methods [5]. Soponpongpipat et al. conducted the optimum thickness analysis of air conditioning duct's insulation, which composes of the layer of rubber and fiber glass insulator, by means of thermo-economics method. The effects of heat transfer coefficient at inside and outside of duct on the optimum thickness of these insulators were studied. The research was done by considering the insulation's optimum thickness of circular galvanized steel duct. The duct diameter of 0.5 m with rubber insulator (k=0.035 W m^{-1} K^{-1}) and fiberglass insulator (k=0.045 W m^{-1} K^{-1}) was selected to show the study results. In order to study the change in optimum thickness when convective heat transfer coefficients were varied, the inside and outside duct convective heat transfer coefficient of 6, 10, 14, 18 and 22 W m^{-2} K^{-1} were selected for calculation of optimum thickness. They demonstrated that the variation of inside and outside duct convective heat transfer coefficient does not affect optimum thickness but net saving increases when inside and outside duct convective heat transfer coefficient increases [6]. Keçebaş et al. [7] calculated the optimum insulation thickness of pipes used in district heating pipeline networks, energy savings over a lifetime of 10 years, and payback periods for the five different pipe sizes and four different fuel types in the city of Afyonkarahisar/Turkey. An optimization model