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Thermal Behaviour of Concrete Walls Around all Cardinal Orientations and Optimal Thickness of Insulation from an Economic Point of View

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Abstract

In this study, it is examined how the thermal insulation and other parameters, such as the orientation of external surfaces and the outdoor/indoor environmental conditions, affect the energy performance of building walls. The analysed assemblies correspond to externally insulated concrete walls, at all cardinal orientations. Their thermal performance is assessed in terms of annual heat flows to maintain the system in balance, while the dynamic thermal inertia parameters (decrement factor and time lag) are also determined. For the aims of this study a one-dimensional lumped model has been adopted by using the finite element method. The analysis also assesses the optimal thickness of the thermal insulating layer from an economic point of view, during the expected lifespan of building structures. Evidently, the varying insulation thickness and orientation of wall configurations, affect the initial cost of the structure installation and the operation cost of the energy consumption (natural gas and electricity).

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Keywords: thermal analysis; conrete walls; surfaces' orientation; walls' insulation thickness; lifetime cycle cost analysis

1. Introduction

In the last few years, serious efforts and resources have been invested in the development and implementation of energy-efficient designs. Maintaining an adequate indoor environment is decisive, and *HVAC* systems can be utilized to that effect. Although the adoption of electromechanical equipment was shown to be valuable, environmental

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Nomenclature

A	surface area, where $A = 1$ [m^2]
d	layer thickness (d_M for the masonry layer and d_I for the insulation layer) [cm]
k	thermal conductivity, heat transfer coefficient due to conduction [W/(m·K)]
ρ	bulk density [kg/m^3]
C_p	specific heat capacity at constant pressure [MJ/(kg·K)]
h_e	exterior surface heat transfer coefficient due to combined convection and radiation [W/(m^2·K)]
h_i	interior surface heat transfer coefficient due to combined convection and radiation [W/(m^2·K)]
R	thermal resistance [K/W]
C	thermal capacitance [J/K]
q_{sol}	incident solar radiation per unit surface of a wall [W/m^2]
α_{sol}	solar absorptivity coefficient [-]
$T_{sol\text{-}air}$	sol-air temperature [^{o}C]
T_{out}	ambient-air temperature [^{o}C]
T_e	exterior surface temperature [^{o}C]
T_i	interior surface temperature [^{o}C]
T_{in}	indoor temperature [^{o}C]
$T_{min/max}$	minimum/maximum temperature value for a specific day period [^{o}C]
f	decrement factor [-]
φ	time lag [h]
Q	heat flow per unit of wall surface [W/m^2]
E	transferred energy per unit of wall surface [J/m^2]
Δt	time step, taken equal to $\Delta t = 15$ [min]
t	elapsed time over a period of 1 year [s]
P_{day}	day period, where $P_{day} = 86400$ [s]
v	ordinary frequency, where $v = 1 / P_{day} = 1 / 86400$ [cycles/s]
ω	angular frequency or rotational velocity, where $\omega = (2\cdot\pi) / P_{day} = (2\cdot\pi) / 86400$ [rad/s]
n	the normal vector of a boundary
C_g	global costs [€]
C_i	initial costs [€]
$C_{a,I}$	annual costs [€]
$V_{f,\tau}$	final value [€]
R_d	discount rate, assumed to be $R_d = 0.06$ [-]
$p_{E,I}$	energy price [€]
τ	calculation period, assumed to be $\tau = 20$ [years]

issues arisen the last few decades, such as CO_2 emissions, city smog and climate alteration, as well as limited energy supply, have amended the way in which buildings should be designed (maintaining the prevailing energy consumption is not a rational practice). Therefore, engineers and designers search for solutions that encompass the passive/active thermal response of the building shell. The building shell is the physical boundary between the outdoor environment and the inside, and if used properly, it can efficiently moderate the need for energy. However, predicting the thermal behaviour of a building is a complicated matter, as it is affected by several construction and design parameters, such as the building's envelope structure and shape, its orientation, as well as the climatic data of the region and the surrounding environmental barriers/constraints[1]. The shell's (walls, floors, roofs, etc.) geometrical characteristics and thermophysical properties demonstrate an essential role in this investigation; decisions on masonry and insulation result to a dissimilar evolution of heat through their structure. One must also consider the impact of solar radiation on the thermal response of wall components and how they are influenced by the afore-mentioned attributes and their orientation, as well as the optical properties of their exterior coating[2]. Last but not least, the imposed indoor temperature settings within building enclosures should be approached carefully.