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Research Paper

Thermal simulation of a social dwelling in Chile: Effect of the thermal zone and the temperature-dependant thermophysical properties of light envelope materials

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HIGHLIGHTS

- Temperature-dependent thermal properties of building materials were measured.
- Thermal conductivity of EPS is more sensitive to temperature variation.
- The envelope of a social dwelling in each thermal zone from Chile was simulated.
- In Southern Zones, thermal regulated envelopes help to maintain comfort.
- In Northern Zones, thermal regulated envelopes fail to maintain thermal comfort.

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ABSTRACT

As in most countries, Chile exhibits a continuous growth of energy demand, although nowadays the country does not have enough conventional energy sources to supply it. For this reason, energy saving approaches in the residential sector have been encouraged. One of the solutions to improve the energy performance of the buildings is to decrease wasting energy through the building's envelope, therefore the thermal properties of materials used in building envelopes must be analyzed to evaluate the thermal response of houses. Normally, the thermal envelope of a social house in Chile is made of brick or wood along with light materials such as fiber cement, plasterboard, and thermal insulating materials as polystyrene foam. The experimental part of this work deals with the measurement of the thermal conductivity and thermal diffusivity of the aforementioned light materials in a temperature range from −5 °C to 40 °C through the transient line heat source method. The experimental results allowed the identification of 10–20% variation of those thermophysical properties. The response of the thermal envelope and the inner temperature of a social dwelling under seven different climatological conditions was evaluated through transient simulations with EnergyPlus. The results allowed to identify that the dwellings located in hotter zones are prone to having higher temperatures than the comfort temperature, and the recommendations of the thermal regulations in Chile are more effective in the colder thermal zones 6 and 7.

1. Introduction

Most of the existing buildings are responsible for an important share of the overall energy consumption, and they generate a large proportion of the greenhouse effect in the world. In developed countries the buildings contribution to total energy consumption is between 20% and 40% [1]. In Europe, buildings, commercial and residential, account for 38.7% of the total energy consumption [2], and in US commercial buildings alone expend approximately 18% of the total energy consumption [3]. Buildings generate a large proportion of the greenhouse gas in the world, and that it is why the International Energy Agency has claimed that the building sector must reduce its total CO_2 emissions by 60% in 2050 to limit global temperature rise to 2 °C [4].

In Chile during the last decade the consumption of electrical energy in the residential sector has shared 16% of the demand electrical energy [5]. The average consumption of energy, including all

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Nomenclature

U	conductive thermal transmittance
C_z	product of the density and specific heat of air
N_{sl}	number of convective internal loads
N_{surf}	number of zone surfaces
N_{zones}	number of zones
$\dot{Q}_i$	convective thermal load i
h_i	convective heat transfer coefficient in zone i
A_i	area of surface i
T_{si}	temperature of surface i
T_{zi}	temperature of zone i
$\dot{m}_i$	mass flow due to interzone air mixing
$\dot{m}_{\mathrm{inf}}$	mass flow due to infiltration of outside air
T_∞	ambient temperature
T_z^t	temperature of zone at present time step
T_z^{old}	temperature of zone at a previous time step
δt	envelope time discretization
k_E	thermal conductivity of the east node
k_W	thermal conductivity of the west node
Δx	spatial discretization
Δt	zone time discretization
Fo	Fourier number ($\alpha\Delta t/\Delta x^2$)
$\dot{Q}_{\mathrm{sys}}$	air systems output

h_c	convective coefficient for smooth surfaces
h_n	natural convective coefficient
$h_{c,r}$	convective coefficient for roughened surfaces
R_f	dimensionless factor which accounts for the roughness of the surface
V_z	wind velocity
V_{met}	average meteorological wind velocity
a, b	constants that depend on wind direction
ΔT	temperature difference
σ	inclination angle of the surface
z	altitude, height above ground
α	wind speed profile exponent at the site
δ	wind speed profile boundary layer thickness at the site
z_{met}	height above ground of the measuring device at the meteorological station
α_{met}	wind speed measured at the meteorological station
δ_{met}	wind speed profile boundary layer thickness at the meteorological station
k	thermal conductivity
C_p	specific heat capacity
ρ	density
T	temperature

sources, of a house in Chile is 10,232 kW h/year. This value is considered high and it can be explained by the share of the use of wood as an energy source (46.6%) in the south of the country, mainly due to its lower price and availability in comparison with other sources. In southern Chile, wood is used mainly to maintain thermal comfort conditions in houses [6].

One of the main solutions to improve the energy performance of a building is to manage the heat flow through its thermal envelope. Most energy used in the residential sector is mainly for space heating and cooling, and therefore, to reduce energy consumption energy-smart house wall systems are required [7]. A high performance building envelope is one of the prerequisites and foundation of a zero energy building (ZEB). Near ZEB is a high energy performance building that requires a very small amount of energy, and its energy needs are covered by energy coming from renewable sources [8]. A building envelope includes mainly the transparent and non-transparent one, also called as opaque envelope, which it is in contact with the outside environment; they can also be further classified into external envelopes and internal envelopes [9]. Two main functions that envelopes must fulfill from the energy-saving perspective are (i) preventing heat loss from the indoor environment, and (ii) managing solar gain. Regarding the first function, the main property of the building envelope to look at is the thermal insulation capability, usually expressed by the thermal transmittance. With respect to the solar gain, the main property of the building envelope to be concern about is thermal inertia [10].

Traditional analytical methods are not useful when temperature dependent thermophysical properties and variable weather conditions are considered. Among all ASHRAE cooling load methods, the heat balance method is recognized as the most rigorous and accurate method that establishes the energy balance equations for a building, based on the first principle of thermodynamic [11]. Therefore, an alternative to analyze temperature variation and energy consumption in buildings is to use a supported computational tool such as EnergyPlus. The numerical predictions of this open-source software have been validated with experimental measurements in several related studies [12–15]. EnergyPlus has even been used to validate a proposed model, which describes the inner radiation effect on the external envelopes of a building [16]. However, the importance of making an adequate refinement of space and time, to obtain realistic numerical predictions, has been pointed out [17,18]. Merely computational studies have been performed. Obyn and Moeseke [19] evaluated the effect of convective heat transfer coefficient models on heating and cooling demands and maximal loads in a standard office building by using TRNSYS 17. The authors analyzed several types of envelope, orientation and internal gains levels to evaluate the impact of the convective models. Nan et al. [20] carried out the calculation of energy demand in a domestic dwelling considering details such as occupancy pattern, lighting and appliance schedule through the ESP-r building simulation software.

Thermal properties of materials used in building envelopes must be analyzed in order to evaluate the thermal response of the construction system. This thermal characterization is a key point during the design phase of the building. It is important to test materials that will be used in the construction of building envelopes before implementing them [21]. The present work is focused first on the thermal characterization of the materials of the thermal envelope. Especially, the thermal properties of the lighter materials are studied as a function of temperature (−5 °C to 40 °C). The second part of the paper deals with the transient simulation with EnergyPlus of a social dwelling that complies with the Chilean thermal regulations, located in the thermal zones into which the country is divided. The results are presented for each thermal zone as transient temperature during a week of each season and the transient temperature distribution along a wall of the thermal envelope during a chosen day of the seasons.

2. Thermal regulation of dwellings in Chile

Due to its geographical position with respect to high pressure zones, the presence of a polar front and the influence of the Pacific Ocean and the Andes mountains, Chile has a variety of climates. The elevation of the western coast mountains do not allow the flow