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Hygrothermal analysis of technical solutions for insulating the opaque building envelope

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Abstract

The application of insulating materials for energy refurbishment of buildings improves the thermal transmittance of the envelope. However, if not properly planned and realized, it could reduce the wall's drying potential, modifying its original features and leaving it generally more humid. This can lead to moisture damages, humid insulation material and risk of mould growth. To avoid any problem related to the increased presence of water in the building envelope, it becomes therefore essential to perform the so-called hygrothermal assessments. In this regard, the international standards offer, beside the traditional Glaser method based on the mere vapour transport, the use of dynamic hygrothermal simulations. These allow to simultaneously consider the transport and storage of heat and moisture in building materials, the influence of climate (including rain and solar radiation in different locations), user behaviour and initial conditions. The aim of this paper is to compare Glaser and dynamic methods and to highlight their advantages and disadvantages, considering the different approaches to the evaluation not only of superficial and interstitial condensation, but also of durability, considering biological attack, freeze/thaw cycles, corrosion, etc.

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Keywords: hygrothermal simulation; insulation system; Glaser method; WUFI®Pro.

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Nomenclature

A	water absorption coefficient [$kg/m^2h^{0.5}$]	t	time [s]
c	specific heat capacity [J/kgK]	T	absolute temperature [K]
D_φ	liquid conduction coefficient [kg/m s]	w	water content [kg/m^3]
U	thermal transmittance [W/m^2K]	δ_p	water vapour permeability [kg/m s Pa]
$f_{risk,max}$	risk temperature factor [-]	ε	porosity [m^3/m^3]
H	total enthalpy [J/m^3]	λ	thermal conductivity [W/mK]
h_v	evaporation heat of water [J/kg]	μ	vapour resistant factor [-]
p_{sat}	saturation vapour pressure[Pa]	ρ	density [kg/m^3]
RH	relative humidity percentage [%]	φ	relative humidity [-]
R_{critic}	risk minimum resistance [m^2K/W]		

1. Introduction

Recent studies [1] have shown that buildings, dated before 1970, are about 60% of the total number of existing ones erected in Italy (the amount rises to more than 80% if considering buildings of the ’80s). These constructions are strongly responsible for the consumption of more than 40% of energy and 50% of air pollutant emissions, due to significant heat losses through the envelope [2]. For this reason, the increase of the energy performance of assemblies has been assuming a key role in improving energy efficiency of the whole building. Though, envelope refurbishment needs a complex design, which considers not only the immediate reduction of heat losses, but also specific issues such as durability, sustainability, users’ health and comfort. The energy refurbishment consists in adding thermal insulation on roofs, basements and walls, either on the external or the internal side of the envelope. The standard rehabilitation is represented by the application of exterior thermal insulation, which eliminates thermal bridges, increases thermal inertia and decreases the risk of condensation and mould on interior surfaces [3]. However, for the preservation of the architectural heritage, interior thermal insulation becomes essential, even though it has not the same advantages of exterior insulation [4]. Sometimes also cavity insulation is used for walls with an air gap, even though it represents an irreversible solution. It has similar features of the exterior insulation, but the humidity stress of the external layer increases, the thermal bridges are not eliminated and the moisture flow is reversed, due to solar radiation [5]. Each of these applications may have other negative consequences on the envelope performances: loss of vapour permeability, humid insulation materials and moisture damages, which might lead to biological, chemical, or physical degradation of the assembly [6]. Hence, hygrothermal evaluations are extremely important to predict the effects of new insulating materials on existing buildings, by considering several factors, such as environmental and climatic loads, indoor moisture level, initial conditions, moisture accumulation of materials, degradation mechanisms, etc. [7].

Hygrothermal analysis could be performed by means of laboratory tests and on-site assessments, which are expensive and long-lasting. For the design process these two methods are replaceable by Glaser method and dynamic simulations. Glaser method is a simplified procedure, based on pure diffusion moisture transport in one-dimensional steady-state condition. This method ignores some issues, such as moisture and heat accumulation in materials and built-in moisture. Moreover, it does not consider the dependence of material properties on humidity and temperature, the capillary transport of liquid water and the rising damp [8]. In order to overcome the limits of steady-state dew-point calculations and to better predict the climate dependent moisture behaviour of construction assemblies, in the last decades dynamic simulations have been developed. Unlike Glaser method, they consider the latent heat exchange, the convection air movements in air gaps and the weather loads (e.g. solar radiation, wind and driving rain). Dynamic simulations enable the analysis of: interstitial condensation in variable regime, influence of solar radiation and rain on the vapour migration, phenomena related to the drying of the structures and users’ behaviour [9].

In this paper, a study on the hygrothermal behaviour of insulation techniques applied to old buildings masonry walls in different Italian climatic conditions is presented. This analysis was performed to evaluate the influence of some energy refurbishments that could increase the envelope thermal resistance, but also decrease its hygrothermal