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Moisture behavior of polystyrene insulation in below-grade application

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ABSTRACT

Expanded polystyrene (EPS) and extruded polystyrene (XPS) are common insulation materials used in thermal insulation systems for below-grade applications. Moisture control components in these systems sometimes fail, resulting in moisture exposure to the surrounding insulation. Although there are several laboratory methods proposed in the literature on the determination of moisture content in polystyrene insulation, the correlations between laboratory data and field data are not evaluated in detail. This paper first conducted an analysis on such correlations and provided a comparison on the laboratory methods defined in different standards. Based on the findings on the correlation study, the criteria on the moisture behavior of polystyrene insulation setting in two main building codes (ASHRAE 90.1 and ASCE 32) that utilize the laboratory data and specific test standards were discussed in detail. Recommendations on the test methods that can better correlate the laboratory data with long-term performance were also present in this paper and these improvements would be able to provide more appropriate information to the building codes.

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1. Introduction

Expanded polystyrene (EPS) and extruded polystyrene (XPS) are insulation materials used in thermal insulation systems for building envelopes, below-grade foundations, and inverted roofs. Water absorption is a key factor causing a deterioration of the insulation's thermal performance for both XPS and EPS insulation [1,2]. Laboratory test results of the water absorption of XPS and EPS are normally used as guidelines for the design and specification of the insulation systems applications [3]. These data are the key reference considered in building code and regulatory developments. However, in most cases, the data from laboratory tests for the moisture content in insulation samples are weakly correlated with the behavior of insulation in the field [1,3].

In the previous work of the authors of this paper, a large set of data has been collected from 56 studies in the open domain literature that pertain to EPS and XPS insulation operating in environments with potential moisture ingress. 36 of the studies were included for the moisture analysis, 31 were included in the thermal analysis, and 10 of the studies were used for both moisture and thermal analysis. According to the set of data published in below-grade applications, most of the field data are provided for the performance of insulation after three service years, while most of the laboratory data are obtained within one year of testing in the lab. Therefore, an analysis of the correlations between laboratory data and field data is required to highlight some of the similarities and differences, and it will serve to explain later in this paper how to correlate the data from the lab with the long-term performance of EPS and XPS insulation. Further, according to the correlations between the lab and the field data on the moisture content in XPS and EPS insulation, the use of laboratory data in two-commonly used building codes (ASHRAE 90.1 [4] and ASCE 32-01 [5]) are investigated in detail. In order to better correlate the laboratory data with the field performance, it is suggested to consider different test standards, revise current standards and operate some novel tests in the building codes to help contractor or designer make a more appropriate selection of the building insulation materials.

2. Glossary and important definitions

2.1. Moisture ingress

Moisture stays in insulation materials in three possible phases: water vapor (gas) phase, liquid water phase and solid phase, and the absorbed moisture would greatly influence the thermal performance of insulation when the moisture exist as liquid phase or solid phase [6]. The moisture ingress mentioned throughout this paper considers primarily the moisture content in the liquid phase. Common applications of thermal insulation systems include building insulation envelopes, roof insulation, and below-grade insulation. In building insulation envelopes, the moisture ingress is mainly initiated by the water vapor transmission and the exposure to a considerable amount of rain. The condensation of water vapor may occur within the insulation material. In most below-grade applications, where the insulation is in direct contact with water in the liquid phase, the liquid water transmission is dominant. In some other applications, such as roofs or around mechanical refrigeration units, the moisture ingress is a combination of water vapor and water liquid transmissions.

2.2. Increase of moisture content due to transmission of water vapor

The transmission of water vapor is the result of the water vapor pressure gradients and the air motion. For most closed-cell, or partial closed-cell insulation, such as XPS and EPS, the air motion is fairly minimal, and there is only a small portion of water vapor transmitted into the insulation due to this air motion. The difference in the partial pressure of the water vapor in the air, which is caused by temperature and humidity gradients in the air surrounding the insulation materials, is the primary force for water vapor ingress into the insulation. Once the water vapor comes in contact with a cold surface point, either within or adjacent to the insulation system, it can condense to the liquid phase if the surface point temperature is below the dew point temperature of the surrounding air. Sorption isotherm and water retention curves are normally considered when evaluating the moisture storage capacity of materials.

2.3. The moisture storage function

Hygroscopic sorption isotherm tests are normally applied to the measurements of building insulations installed with direct contact of moist air when the relative humidity is lower than 80%. In the study of moisture content, research [7] pointed out that in most building materials, all three phenomenon occur: absorption, capillarity and diffusion. The trends show that when the RH is from 0% to 30%, the moisture content by mass increases very fast because of the initial mono and multilayer absorption processes, but the series do not show remarkable changes between 50% and 80%. Some researches [7–10] propose that the moisture content of the insulation specimens by mass in the climate chamber tests indicates a linear correlation with the square root of time, which gives good agreements with the actual performance of the envelope insula-