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Hot box measurements of pumice aggregate concrete hollow block walls

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HIGHLIGHTS

▶ We studied performance of pumice aggregate concrete block wall with hot box method.
▶ Temperature and humidity were monitored in the hollows of test blocks.
▶ Hollows have a lower thermal transmittance than the lightweight solid parts.
▶ Porous material keeps moisture within its structure and dries slower from inside.
▶ Lower and upper courses demonstrate slightly different hygrothermal behaviour.

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ABSTRACT

Due to its relatively low thermal conductivity characteristics and being a local product, pumice aggregate concrete (PAC) blocks are increasingly used as a masonry wall unit in Turkey. However, there is limited technical and scientific knowledge on hygrothermal performance of PAC blocks. A research project is conducted to study hygrothermal performance of PAC block walls using a calibrated hot box method. Temperature and humidity measurements were carried out at the surfaces of the test wall and in the hollows of blocks on different courses. The results, in general, indicate that the hollows of blocks perform better in terms of thermal transmittance than the lightweight solid parts of them. Noticeable changes are observed in hygrothermal behaviour of the lower and the upper courses depending on the indoor and outdoor climate test conditions. The heterogeneous material and rough surface characteristics of the blocks, in addition to the wet construction type of block wall are the most problematic issues that make measurements and assessments difficult.

1. Introduction

Designing energy efficient buildings is one of the crucial issues for a sustainable construction. In order to save energy it is important to use local sources and building products with low embodied energy, and build envelopes which achieve high thermal performance during the use phase of the buildings. Pumice, a type of porous volcanic tuff mineral which occurs naturally in an expanded form, is found in various regions of Turkey [1]. Being a local material with lightweight and relatively low thermal conductivity characteristics, it is used for the production of pumice aggregate concrete (PAC) blocks. In Turkey, buildings, whether low or high rise, are mostly constructed with in situ reinforced concrete structural frames and infill masonry walls of fired-clay hollow bricks, autoclaved aerated concrete blocks, or PAC blocks, the use of which have been expanded during the last decade. However, there is a lack of reliable scientific and technical information on PAC blocks in general, and knowledge about hygrothermal performance of external walls built with these blocks in particular.

Through experimental works, computational studies, and field inspections, an extensive research project has been conducted to investigate hygrothermal performance, energy and economic efficiency through life cycle with regard to sustainability and environmental performance. In the research program in general, a holistic and integrated approach is adopted. Thus, in measuring hygrothermal performance, laboratory works are held at different scales including measurements of material properties, investigation of the behaviour of hollow block wall component, and performance of wall as a whole system. Moisture and heat transfer through wall is measured using a hot box method. Thermal conductivity measurements are made by means of a guarded hot plate method. Thermal and moisture characteristics of pumice aggregate concrete

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material are tested using standard methods. This paper particularly focuses on the hot box measurements of this research project. In these measurements, humidity sensors placed within the hollows of the PAC blocks and thermocouples installed on the surfaces of both hollows and PAC blocks located at different courses of the test wall were used to investigate the hygrothermal behaviour under controlled indoor and outdoor room conditions of the calibrated hot box. In the paper, results obtained from these measurements are presented and discussed in detail.

Some of the studies concerning similar objectives, methods, or type of materials are briefly as follows. Fazio et al. designed and developed an environmental chamber for measuring the heat flow and temperature to investigate the building envelope performance. Apart from the other calibration tests, a wood stud wall was tested to observe the performance of environmental chamber in the guarded hot box mode of operation [2]. Some other researchers have also investigated hygrothermal performance of timber-framed wall assemblies [3–5]. In these studies, hot box tests were carried out simulating local climate conditions particularly to compare and verify the numerical analysis results of various computer simulation programs. In addition to wall surface, indoor and outdoor temperatures, and relative humidities, heat flow and moisture content measurements were also performed in some of them. Furthermore, there are some research studies on thermal performance of hollow block and perforated brick wall units in which hot box tests were utilised to validate numerical models [6–8]. Bondi and Stefanizzi studied water vapour transfer resistance of hollow brick by numerical model, and experimentally by weighing the dehumidifying agent in the dry room and the water container in the wet room of a climate chamber [9]. Künzel et al.'s research, on the other hand, focused on the moisture buffering effect of indoor components [10]. In this respect, they monitored surface and air temperature, air humidity, and heat flow within the environmentally controlled room to validate a numerical model. Using laboratory tests, Özdeniz investigated the hygrothermal performance of a new concrete wall block design having pumice as aggregate. Apart from material characterisation tests, hot box measurements were conducted on different assemblies of both newly-designed and ordinary concrete wall blocks [11]. Bomberg and Thorsell proposed an integrated methodology to evaluate the energy performance of different exterior wall types by use of hot box measurement and computer simulation together. Apart from the standard steady-state evaluations, the effect of air infiltration was also taken into consideration [12,13]. Steady state and dynamic thermal performance of walls with hot box measurements were carried out at the Oak Ridge National Laboratory (ORNL). They tested different types of walls including concrete masonry units and declared the *R*-value results within a database [14].

In some of this research, experimental work was mainly utilised to compare or validate the numerical analysis of heat transfer through walls, and additionally, test conditions or test specimens were specifically designed to simulate those modelling conditions. On the other hand, in some other research, solely experimental investigations were made. However, almost none of those papers discussed the experimental work and its results in detail. Besides, very few of them covered wet masonry wall construction which generally based on thermal performance measurements.

2. Experimental

The hygrothermal behaviour of heterogeneous PAC block wall assembly is investigated using a calibrated hot box method at operating conditions typical of normal building applications. Two test walls were built in consecutive years. Monitoring of test walls were carried out for approximately two months after a drying period of two to three months during which measures were taken for accelerating the drying process of wet masonry application. The experimental set-up is composed of: (i) climate chamber, (ii) test wall, and (iii) measuring devices.

2.1. Climate chamber

A custom made walk-in type Weiss-Technik climate chamber was employed for this experimental research work. The temperature in the climate chamber can be regulated ranging between +10 °C and +30 °C for the indoor room and −40 °C and +60 °C for the outdoor room when the relative humidity control unit is disabled. The relative humidity can be set between 20% and 90% on condition that the temperature in both rooms is above 10 °C. The climate chamber is working with a specific tolerance for adjusting and stabilizing the conditions set for both indoor and outdoor rooms. The machine is automatically activated when the temperature deviates ±1 °C and the humidity level deviates ±5% from the set conditions. The uniform distribution of the indoor and outdoor set-up conditions through spaces is maintained by the fans in both rooms of the chamber.

2.2. Test walls

Two successive test walls measuring 19 cm × 120 cm × 240 cm (width × length × height) were built, separating indoor and outdoor rooms. Cement mortar was used at the vertical sides and base connections of the masonry wall. The gap left on the upper part of the wall was filled with expanded polystyrene and the connections with the ceiling were sealed with polyurethane foam. In Figs. 1 and 2, the test wall built in the climate chamber and a test block with installed sensors is shown, respectively.

Test walls were built using two different PAC blocks having three-row hollows, those which are the most widely used types in the construction market of Turkey. Standard blocks having tongue and groove sides which enable mortarless interlocking vertical joints were measuring 185 mm × 390 mm × 190 mm and 185 mm × 330 mm × 240 mm respectively (width × length × height). In selecting the sizes, the primary criterion was to test the blocks having widths mostly preferred in the construction applications of external walls, while it was also considered to employ blocks having equal widths for both types. Blocks were laid on a ~10 mm thick cement bedding mortar and overlapped in alternate courses. The blocks, which have hollows arranged in a staggered pattern for avoiding thermal bridges, are closed with ~1 cm thick layer on the upper surface in order to prevent the hollows from being filled with the bedding mortar. In the block production, the concrete ingredients are: pumice aggregate with sizes ranging between 3–8 mm and 8–16 mm, ordinary portland cement, mixing water, and very small amounts of iron oxide giving the blocks their slightly reddish colour. During the process of producing the PAC blocks, slightly moist aggregates are added to the low viscous cement paste, thus hardly any segregation occurs in the mixture. Blocks are then formed by injection and pressing through steel mould and subsequent vibration processes. Wet blocks are finally air-dried in a chamber for 72 h. The material characteristics

Fig. 1. Test wall in the climate chamber.