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Determination of thermal characteristics of standard and improved hollow concrete blocks using different measurement techniques

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ABSTRACT

The lighter weight, improved thermal properties and better acoustic insulation of hollow-core concrete blocks are few of the characteristics that one encounters when comparing them to traditional Maltese globigerina limestone solid blocks. As a result, hollow concrete blocks have recently been in greater demand. However, their transmittance, or U-value, is still quite high and does not meet the minimum energy requirements for constructing new buildings. This paper is focused on the investigation of the thermal properties of a new building block, developed as part of a nationally-funded research project ThermHCB, with the aim of improving the U-value of such blocks without changing their compressive strength, physical dimensions or manufacturing process. Measurement techniques were applied to obtain comparative values of the thermal transmittance for standard and improved HCBs, using different EN and draft standards. Compressive testing was carried out concurrently in order to ensure that the minimum benchmark compressive strength was reached. The comparison between these results provides information on the reliability of the methodologies used to determine the thermal properties of building elements in-situ, without having to conduct such tests in a laboratory hot box setup.

1. Introduction

In a report issued by the International Energy Agency 1991 “Energy Efficiency and the Environment”, it is stated that in most countries, construction activities cover between 1% and 3% of the existing buildings per annum. It is no surprise that as stated by Goldberg et al. in 1988 “Energy and a Sustainable World”, it is cheaper to save an extra unit of energy rather than generating it, considering long-term energy prices.

For the population of Southern Europe, the indoor comfort conditions during summer have always been a priority. Inhabitants from warm and hot climates have always endeavoured to find solutions to reduce indoor temperatures. Hence, the choice of wall materials has been one vital parameter on which summer comfort depends. The thermal properties of building envelopes can be deduced from heat transmission data as declared by manufacturers, which are generally obtained by laboratory measurements or numerical simulations. Whilst thermal conductivity figures of insulation materials are well established, those for components of the building envelope – such as masonry blocks – are less defined. In such cases, the in-situ measurement of thermal transmittance is crucial to have in hand for a correct evaluation of the building envelope's thermal behaviour. This is not to say that laboratory assessment is not a robust methodology, but evaluating the thermal transmittance of building walls under real operating conditions has its usefulness. In-situ measurements of thermal transmittance of buildings have become essential, more so, in high-energy performing buildings, since the variance in value between actual and laboratory/numerically calculated one, affects the building's performance and its economic cost-benefit analysis.

According to the National Statistics Office – Malta (News Release 189/2014), the electrical energy generation and consumption in Malta over the past decade was on average 2.2 million megawatt hours

Abbreviations: U-value, Value of thermal transmittance (W/m^2 K); HCB, Hollow concrete block; HVAC, Heating, ventilation and air-conditioning; ARX-model, Autoregressive model with exogenous inputs; HFM, Heat flow meter method; IRM, Infrared method; OA, Orthogonal array; LECA, Lightweight expanded clay aggregate; EPS, Expanded polystyrene; q, Heat flux (W/m^2); k, Thermal conductivity (W/m K); DT, Temperature differential (K); L, Thickness of material (m); G, Global solar radiation (W/m^2); ACF, Auto-correlation function; CCF, Cross-correlation function; H, Sum of UA-value and convection losses (W/K); UA-value, Value of the product of the U-value and the area perpendicular to the direction of heat transmittance (W/K); A, Area perpendicular to the direction of heat transmittance (m^2); HLC, Total heat loss coefficient (W/K)

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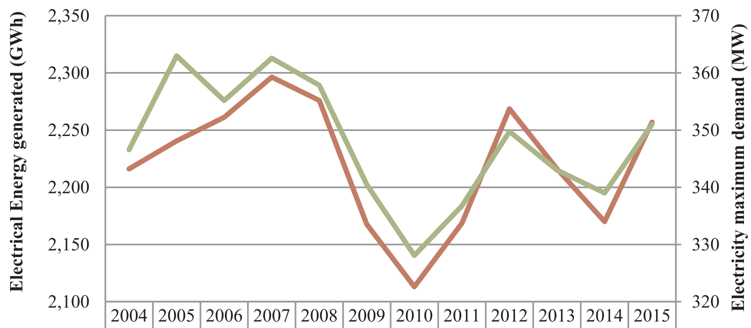

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Electrical Energy generated (GWh)	2,216	2,240	2,261	2,296	2,276	2,168	2,113	2,169	2,269	2,216	2,170	2,257
Electricity maximum demand (MW)	347	363	355	363	358	341	328	337	350	343	339	351

Fig. 1. Electricity generation in Malta between 2004 and 2015 [Compiled from data available at the Regulator for Energy and Water Services (ex-Malta Resources Authority)].

annually. The local percentage of electrical energy use in buildings (residential and commercial) accounts for a considerable proportion of around 60%. For this reason, building energy conservation is important for Malta's sustainable development. It is interesting to note that approximately 20% of all electricity generated occurs in July and August when the temperatures are highest. In order for people to live and work comfortably in their buildings, temperatures are controlled using HVAC systems, thus contributing towards higher energy use. The building envelope plays a vital role in reducing energy consumption in buildings, by regulating the amount of heat flowing through it. In 2012, a 4.6% increase in electricity demand excluding renewables was recorded. Reacting to this growth simply by increasing the generation capacity could lead to economic and environmental consequences [1]. Fig. 1 below shows a graphical interpretation of electricity generation in Malta between 2004 and 2015.

Changes to the masonry units are one of the necessary measures that need to be undertaken if energy savings and efficiency are to be achieved. It is therefore no surprise that thermal characteristics of building envelopes are nowadays under increased scrutiny with the ever growing international concerns over energy and resource conservation. Many studies have been done and are still being carried out to provide new building materials and devise simple ways of constructing appropriate building envelopes with the right thermo-physical properties. The concrete technology can be easily adapted to suit special needs of users by modifying design parameters such as mix proportions, constituent materials and water/cement ratios. Work, on methods of measurements and specific material production, carried out by various researchers has been taken into account for this study. Following is a summary of those works that enabled the organisation and conflation of information as the basis for the testing methodologies adopted for this research study [1].

1. The concept of the full scale testing created by the international collaboration in the context of IEA ECBCS [2], was also applied in this specific research work, whereby two in-situ test cells were constructed in order to analyse the thermal behaviour of different hollow concrete blocks concurrently.
2. The active and passive method procedures, presented in the work of Fazio et al. [3], were influential in opting for the active method chosen for this research methodology, in order to overcome the elaborate equipment required for the passive procedure. Moreover, as seen in the works of Yesilata et al. [4], given that the purpose of the work to be carried out for this study was to compare the U-values of standard and improved HCB walls, the same methodology was implemented for all samples thus eliminating the possible variation in results obtained from applying either of the methods mentioned above.
3. The use of thermal imaging to identify locations and extent of thermal bridging, as well as the use of thermal paste ensuring good contact of the heat flux sensor with the test wall, as applied in the works of Byrne et al. [5], were both adopted in the work carried out for this study. Thermal imaging was used in order to certify that the location on the wall chosen for placement of the heat flux sensor was representative of the heat flow through the entire wall. Methods of setup used in the work of Fang et al. [6] were also applied in the testing methodology of this research. Heat flux sensors were installed making use of masking tape and placed either on the web or on the cavity of the HCBs.
4. In this study, the U-values, obtained from in-situ measurements, were compared to results obtained from hot box measurements and numerical modelling. Similar comparisons were carried out by Baker [7] as presented in his research report. In this way, it was possible to obtain relevant conclusions about estimated thermal transmittances, when comparing theoretical values with actual in-situ measurements. Pulis [8] proposed that this behavioural characteristic is taken into account and theoretical values are compared with actual measured values of resistances of HCBs.
5. One-dimensional heat flow was assumed for this study based on the supposition taken by Vella [9], whereby he stated that given the dimensions of the experimental test cells, one could assume that heat flow in one direction is very close to the real behaviour achieved. Another important factor deriving from Vella's work was the issue of handling and positioning of HCBs on site. In the study presented here, this matter was given prime importance and that is why experiments were carried out on the same shape and dimensions of prototype block with emphasis only on improving the mix of the actual building block.
6. Importance of environmental infiltration rates, as discussed in the work of Becker [10], was particularly considered in this research. In order to limit the amount of air infiltration rates inside the test cells, attention to workmanship at the time of construction was given utmost importance, especially during the placement of mortar on the horizontal and vertical joints. This was also ensured by making use of the service of the same builder throughout the whole course of this research study.
7. In the ThermHCB project, the research partners Galea Curmi Engineering Services Ltd. followed the study presented in the publication of Kato et al. [11] to set up the methodology for the infrared testing, results of which were used in this research work. Prime importance was given to the time period of testing, taken between midnight and 06:00 h in order to avoid direct solar radiation.
8. The experimental structure used in the study of Thouvenel [12] was similar in principle to the in-situ infrared testing setup used for this study. Amongst other considerations, one ought to mention the aspect ratio of the test wall when compared to its thickness vis-a-vis one dimensional analysis, the importance of the heat dispersion onto the test wall when it comes to the position of the heater in the