The Thermal Performance of Ventilated Roofs

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ABSTRACT

The potential for passive cooling of roof slabs incorporating an air cavity is important with respect to thermal comfort. Roof systems in traditional buildings, incorporated a ventilated roof or an air cavity. The concept has been proposed again in contemporary buildings in the construction of roof slabs, using a modular formwork system, where the cast in situ concrete slab is isolated from the screed with the introduction of a ventilated air space. The cavity is primarily intended to curtail the conduction and inward radiation of heat from the intense solar insolation on the concrete roof. An experimental investigation was conducted for summer and winter conditions, where a traditional monolithic slab and a slab incorporating a cavity were analysed. Results indicated that during the cold season, a ventilated cavity looses more heat to the outdoor environment, and is ideally unventilated. It was revealed that in summer the ventilated cavity reduces heat transfer in the flat roofs, improves comfort conditions and potentially reduces the overall cooling load. A strategy for further research on the thermal performance of ventilated flat roofs is proposed, based on further laboratory investigation, and the monitoring and assessment of buildings.

KEYWORDS

ventilated roofs, thermal performance, passive cooling, energy efficiency.

INTRODUCTION

The roof is particularly important with regards to the thermal behaviour of a building, especially when considering heat gain and heat losses in and out of the building through thermal conduction. The heat gains and losses lead to a larger amount of energy consumption in cooling and heating the building. The introduction of a horizontal air cavity in flat roof slabs, can potentially contribute towards passive cooling and improved thermal behaviour in buildings. The air cavity system in roof slabs in contemporary buildings, is inspired from historic and traditional buildings in Malta.

The climate of the Maltese Islands is typical of Mediterranean Islands, with hot dry summers and mild winters. The mean lowest temperature recorded is 11ºC in the winter months, while the mean maximum reaches 35ºC in the summer months. The Relative Humidity is consistently high all year round, ranging between 65% and 80%, with relatively small differences between the summer and winter months. Rainfall is recorded at an average of 502mm, with the winter months being the wettest. The mean sunshine hours average 8 per day. The Maltese islands are also characterized by the strength and frequency of the winds, particularly the cool north westerly and the dry north easterly. (National Statistics office, 2002)

VENTILATED ROOFS

Traditional Buildings

Construction methodologies adopted in historic Roman buildings include the creation of an air chamber through terracotta amphorae under the floor (Bonanno A., 2005), and also raised floors to allow for cooling through cross ventilation. Roof structures incorporating an air cavity are encountered in traditional buildings in Malta. In the agricultural store (Figure 1), the roof structure consists of a primary lower roof structure, and an overlying roof, with a resulting ventilated cavity approximately 650mm high. The roof structure typical of British Military Barracks constructed during the 19th century in Malta (Thake et al, 2005), consists mainly of parallel steel I beams at an approximate interval of 1.2m, with limestone slabs spanning between the steel beams approximately 380mm high (Figure 2). Stone slabs of approximate thickness of 75mm are supported on the lower flanges of the steel beams, while stone slabs of approximate thickness of 100mm are supported on the upper flange of the steel beams, with the overlying “Torba and Diffone” finishing layer. The 300mm high cavity within the roof structure, between the bottom and upper stone slabs is indicated as an “Air Space” in the detailed drawings of the barrack buildings. (Malta National Archives)

Figure 1: Agricultural Store; Ventilated Roof structure

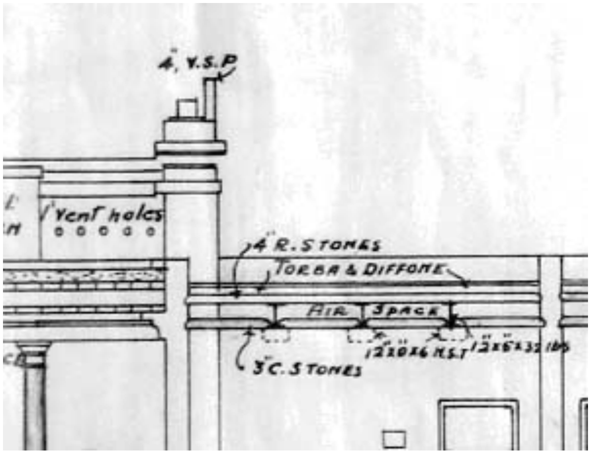

Figure 2: St Andrews Barracks; Detail of Roof Structure. (Malta National Archives)

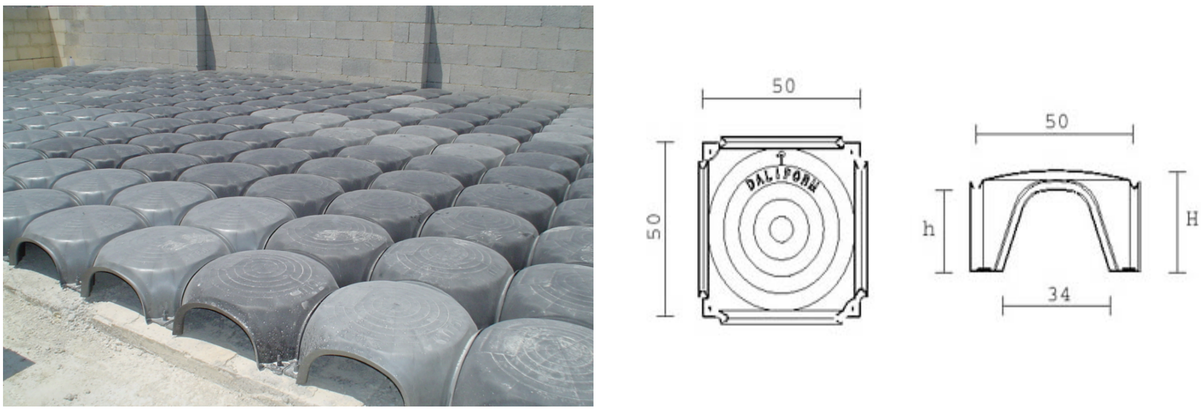

Figure 3: Iglu ® Modular Formwork System (Daliform srl.)

Modern Applications

The concept of a ventilated cavity roof has been proposed in contemporary buildings, by adopting a modular formwork system, consisting of lightweight recycled polypropylene, on which a concrete layer is cast. The interlocking Iglu ® modules (Figure 3) developed by Daliform s.r.l, measure 500mm by 500mm on plan and are available in various heights, ranging from 8cm to 55cm. The 8cm and 12cm modules have a flat top, while the rest have a convex top. The modules are primarily used in the construction of raised ground slabs with a ventilated gap underneath them, and for the creation of a horizontal air cavity on reinforced concrete flat roof slabs. Different types of cavity roofs may be constructed at minimal additional work. Variations include cavity height, and concrete thickness, and the cavity can be either ventilated or non-ventilated. In the case of ventilated cavities, wind velocity and direction are important considerations, and their effectiveness is dependent on site exposure and the orientation of the building.

EXPERIMENTAL INVESTIGATION

Research Methodology

An experimental investigation was conducted in order to investigate the use of the modular system in flat roof construction, and assess the potential for curtailing conduction and inward radiation of heat on the concrete roof. The system presents an innovative way of improving thermal comfort, and potentially reducing on the overall cooling load (Buhagiar & Borg, 2006 and Abela, 2006).

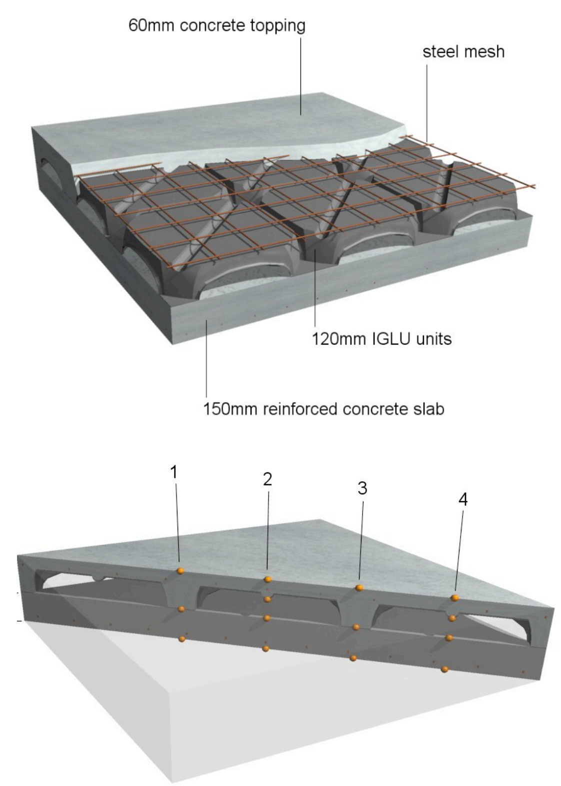

Figure 4: Cavity Roof, and position of thermocouples

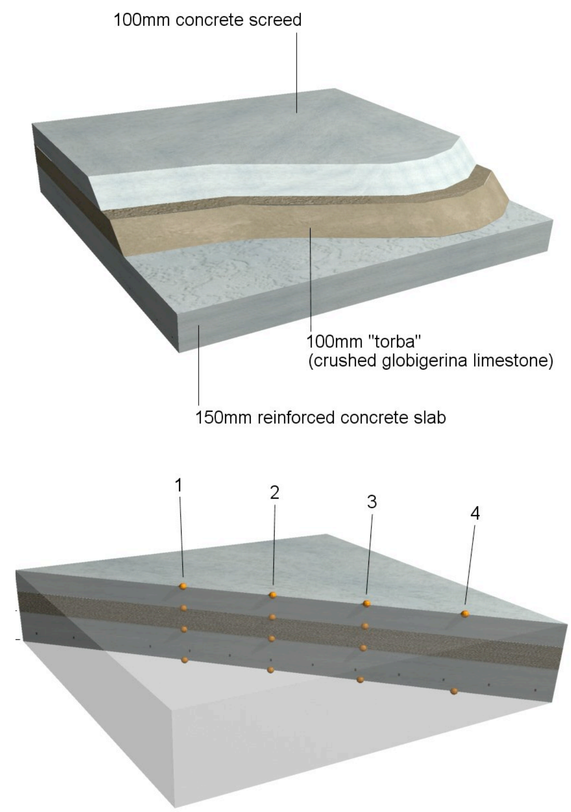

Figure 5: Conventional monolithic roof construction, and position of thermocouples

The experiment was first conducted on a composite slab consisting of a lower reinforced concrete 150mm thick slab, and an overlying reinforced concrete slab cast onto the 120mm thick interlocking modules. The lower slab, measuring 1.5m by 1.5m, was cast using C25 concrete, and was reinforced with a C503 mesh. The overlying 60mm thick slab, was reinforced with an A142 mesh and cast using C25 concrete, onto the 9no. (3x3) modules, that were laid out symmetrically on a 1.5m by 1.5m plan (Figure 4). The same setup was also used to test the monolithic flat roof, consisting of a nominal 150mm reinforced concrete slab, 100mm ‘torba’ and 100mm concrete screed (Figure 5).

The potential for convective cooling was analysed, through an investigation of still air conditions with a closed horizontal cavity, and a ventilated cavity. Two scenarios were considered, namely heat gain and heat loss through the roof, in summer and winter respectively. A temperature difference was created between the top and bottom of the slab, and monitoring was carried out in order to determine the temperature profile over a time frame, using multiple thermocouple heat sensors at different locations. Air and surface temperatures were monitored separately. The test rig included adequate insulation (Figure 6).

The ventilation for each system setup was simulated through three pairs of 65mm diameter holes, that were fitted with motor operated cooling fans, and calibrated with a hand-held anemometer. These induced a vent-flow speed of 1.1m/s, as exit conditions after frictional losses. On the basis of the temperature data obtained an approximation of the U-Value of the composite slabs under laboratory conditions was calculated, together with the thermal conductivity of the elements forming the roof.

Figure 6: Experimental setup in the laboratory.

TABLE 1
Roof type, test parameters & U-values in W/m^{2}K for entire specimen.

Roof Type	Test Parameter	Test Parameter	U Value [W/m^{2}K]
Cavity Roof	Summer	Ventilated	2.36
		Non-ventilated	3.40
	Winter	Ventilated	4.37
		Non-ventilated	3.35
Monolithic Roof	Summer	No cavity	5.19

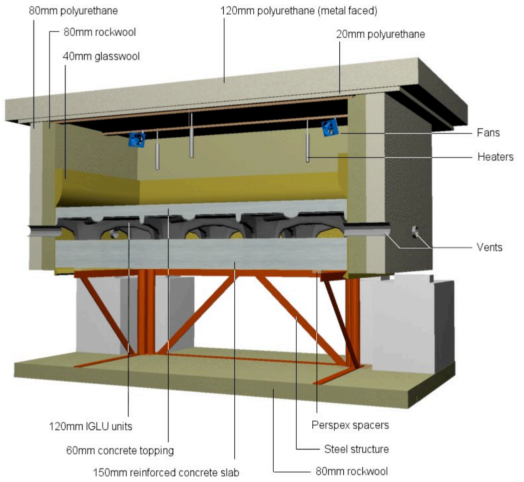

Figure 7 : Test rig setup – Summer Conditions

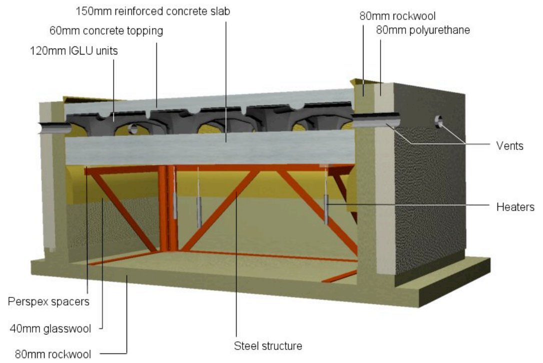

Figure 8: Test rig setup - Winter Conditions

TABLE 2
Thermal conductivity for separate materials.

Roof element	Thermal conductivity, k, [W/mK]
Vaulted 60mm R.C. Slab	1.25
100mm Screed	1.70
Torba (moist)	2.13
R.C. slab	1.62

Results & Analysis

The U value of each specimen was calculated on the basis of the temperature data obtained for each experiment (Table 1). The thermal conductivity, k, of each roof element making up the specimen, was obtained as summarised in Table 2. The ventilated roof has a lower U-value than the non-ventilated roof for summer conditions, (1.04 W/m^2K difference). There is a significant difference of 2.83 W/m^2K between the ventilated system and the monolithic slab and a difference of 1.79W/m^2K between the non-ventilated roof and the monolithic slab, for summer conditions. Greater losses are experienced through the ventilated cavity in winter conditions, therefore suggesting that such cavities are to be closed in winter to reduce heating energy losses. Some ventilation will help reduce condensation within the cavity. The vaulted reinforced concrete slab has a thermal conductivity, k of 1.25 W/mK whilst the conventional 100mm screed has a thermal conductivity of 1.70W/mK.

The evaluation of the U values and thermal conductivity values, was based on the test data, and on relevant assumptions. A critical evaluation of the experimental parameters and methodology was also conducted in view of further investigation.

STRATEGY FOR FURTHER RESEARCH

The strategy for further research is based on two main areas of investigation; laboratory investigation and assessment of actual buildings.

Laboratory Investigation

The values obtained for thermal conductivity require further research, based on the properties of the various materials utilized in roof construction. Further research is proposed, using a similar and refined test setup, and considering different cavity heights, different concrete screed thickness and variations in the ventilation rate. Furthermore, it is planned to investigate the introduction of a reflective foil between the modules and the structural slab, and the effect of various types of insulation materials and thickness of insulation. It is also proposed to assess different roof construction typologies as for example monolithic slabs, hollow concrete slabs, and slabs consisting of hollow concrete blocks supported on parallel inverted T beams.

Building Assessment

Monitoring of actual buildings with ventilated roofs is proposed, in order to assess diurnal and seasonal variations. An investigation of two similar buildings the first with, and the second without ventilated roofs is planned over an extended period of time, in order to complete a comparative assessment. A detailed energy assessment is proposed to assess the efficacy of the ventilated roof systems in buildings. Consideration of specific local conditions in buildings is important. In particular the actual flow rate depends on site location, exposure and various environmental conditions. Studies based also on interviews with the users of the buildings are intended to be conducted in relation to user perception and thermal comfort.

CONCLUSIONS

The static air inside the cavity roof contributes towards reducing thermal conductivity between the structural slab and the screed. During the cold season, a ventilated cavity looses more heat to the outdoor environment, and is ideally unventilated. The ventilated cavity is particularly effective for summer conditions, to dissipate heat resulting from the intense solar radiation, reduces heat transfer in the flat roofs, improves comfort conditions and potentially reduces the overall cooling load. The system requires minimal additional work, and can be effectively implemented in new buildings and in refurbishment projects. The strategy for further investigation is based on detailed laboratory investigation, with reference to various experimental variables, and on the actual monitoring and assessment of buildings.

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