Investigating the Potential for Passive Cooling of Ventilated Roof Systems in Malta

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Investigating the Potential for Passive Cooling of Ventilated Roof Systems in Malta.

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Abstract

This paper explores the potential for passive cooling by manipulating a traditionally monolithic flat roof structure in Malta. This is investigated by isolating the cast in situ structural concrete slab from the topping screed, typically laid to falls, and ventilating the space. A test rig was set up under laboratory conditions where thermal performance was tested for in summer and winter. Results suggest that there is no significant contribution in winter when vents are kept closed but in summer convective cooling reduces indoor surfaces temperatures, alleviating discomfort conditions in upper floors, thus reducing the demand for cooling.

Keywords: passive cooling, ventilated roofs, thermal comfort, energy efficiency.

1.0 INTRODUCTION

In consideration of Malta's typical Mediterranean marine climate, summers are generally unpleasantly hot with an overall high relative humidity level all year round.

Diurnal variations in spring and summer are considerable, ranging from 10-15°C. Relative Humidity is considered high, yet typical of a Mediterranean Island, ranging between 75-95%, with its peak in winter. While solar insolation levels may reach up to 7,800W/m^2 only 13% of the 365 days are with zero air movement. [1]

The Islands' quasi-coastal built up environs therefore already suggest the exploitation of passive cooling through on-shore currents, particularly in spring & summer.

Early Maltese folk, and the latter generation of builders have realised this by exploiting predominant wind directions in the layout of rural farm buildings, typically scooping in the prevailing north to north-westerly winds, where perhaps in truth 'form followed function' in Maltese vernacular architecture [2].

2.0 DESIGN RATIONALE

The background to the study is first outlined tracing the roots of aerated floor systems to their potential for modern day use.

2.1 Roman Inspiration

This paper was inspired from a literature review of such passive systems used since circa 650A.D. by the Romans in Italy. These were primarily intended for raised floors exploiting ground temperatures, which were known to be cooler in summer and warmer in winter, also isolating any rising damp by

Figure 1: raised floor on stump walls with gaping openings for cross-ventilation

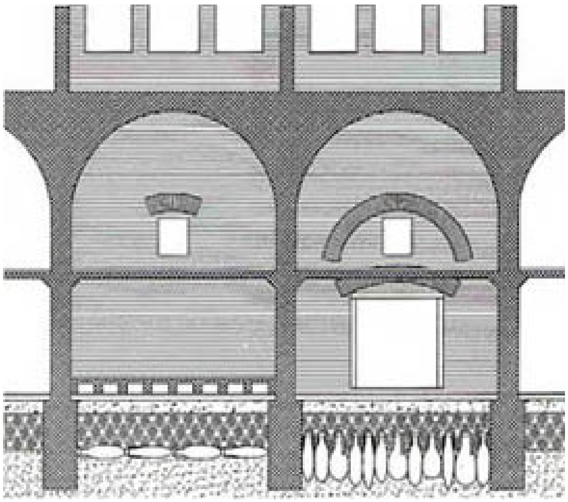


Figure 2: terracotta jugs used as a static air cavity

Figure 3: Amphorae laid vertically and covered with compacted infill material acting as a form of a static air cavity (Rabat Malta).

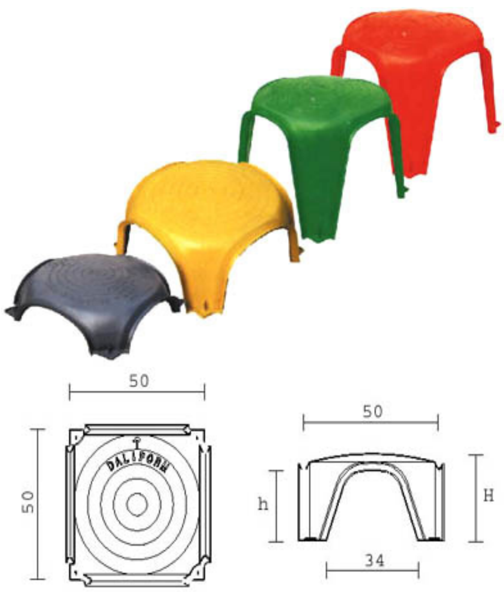


Figure 4: Prefabricated modules come in different sizes ranging from 0.08 to 0.55m on a standard 0.5m square base.

means of cross ventilation through stump walls, or having terracotta amphorae with compacted fill creating a still air chamber equivalent to a cavity, figs 1,2, [3] and 3[4].

2.2 Modern Application

The concept has been proposed again today, as is the case of the modular formwork system, made out of lightweight recycled polypropylene, that was developed by Daliform s.r.l. in Italy. The modular system was trade named Iglu.© [3] because of its geometric form. This comes in different heights on a standard interlocking base of 0.5x0.5m as illustrated in figure 4. It is primarily intended for load-bearing floors and ideal for aerated raised flooring requirements for taking cable management and other services, or simply as a form of insulation, figure 11 refers.

3.0 AIM OF THE STUDY

The scope of the study is however to investigate the potential of using the Iglu© modular system for flat roofs (instead of floors) in Malta. They seem ideal for curtailing conduction and inward radiation of heat from the intense solar insolation beating on the non-insulated monolithic concrete roof. While minimal additional work is required, it presents an innovative way of insulating against adverse weather conditions, alleviating thermal comfort, thus potentially cutting down on the overall cooling load.

3.1 Thermal Considerations

The potential for convective cooling of flat roofs is exploited by investigating the effects of still air conditions (closed horizontal cavity) as opposed to natural/forced ventilation through a raised split cross-section of the two slabs. The upper usable flat reinforced concrete roof screed is isolated by using a single sized module, namely 120mm high.

This four-legged stool is designed to entrain air through the space in a bi-directional movement, across an orthogonal grid layout composed of interlocking modules of 0.5m square (figure 4). Their efficiency depends on surface texture and the difference in temperature between cavity and ambient air. Naturally wind velocity and direction play a central role, their efficacy dependent on the orientation of the building and its site exposure.

3.2 Construction Parameters.

Independently a literature review of case studies reveals the traditional use of such a ventilated roof system albeit using different materials and methodologies (figs 1,2 & 3).

The structural performance and load carrying capacity of the system depend on various criteria that include also the properties of the materials, geometry, slab thickness, reinforcement and load characteristics that are beyond the scope of this paper.

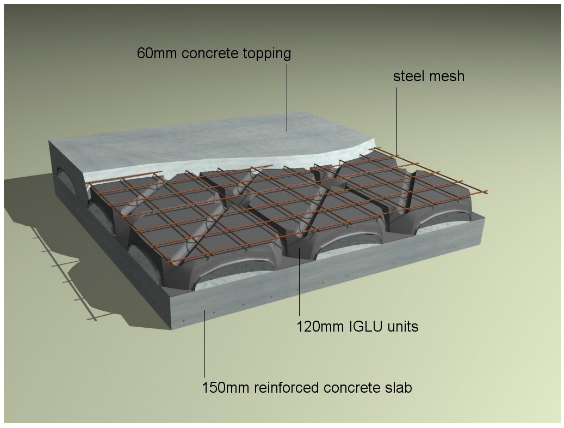
4.0 METHODOLOGY

In order to assess the thermal performance of the composite slab structure physical monitoring was carried out using multiple thermocouple probes at different locations in order to establish the temperature profile through the buffer space over a given time frame. Concurrently air and surface temperatures were also monitored separately. Two scenarios were set up namely for ingress and egress of heat in summer and winter respectively.

4.1 Test Rig Set-up

The experimental set up of the composite slab structure was composed of a lower reinforced concrete slab, and an overlying reinforced concrete slab cast onto the 120mm thick vaulted modules.

The lower 150mm thick 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 cast using C25 concrete, onto the 9no. (3x3) vaulted modules, that were laid out symmetrically, and was reinforced with an A142 mesh. Figures 5,6 refer.



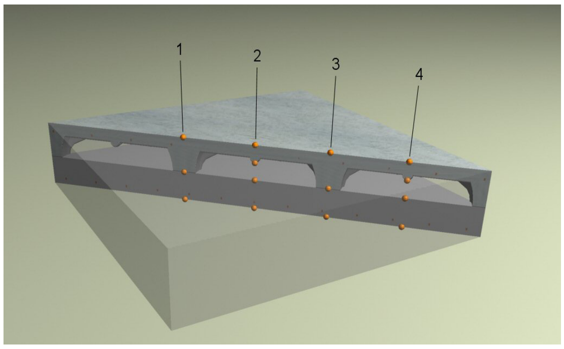
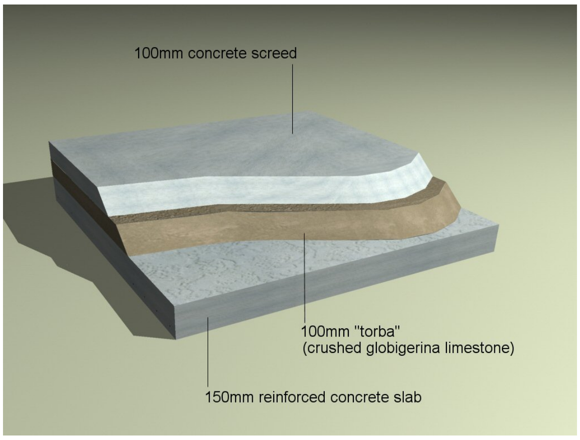
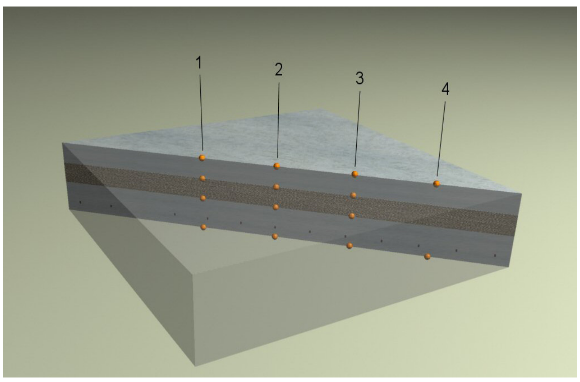
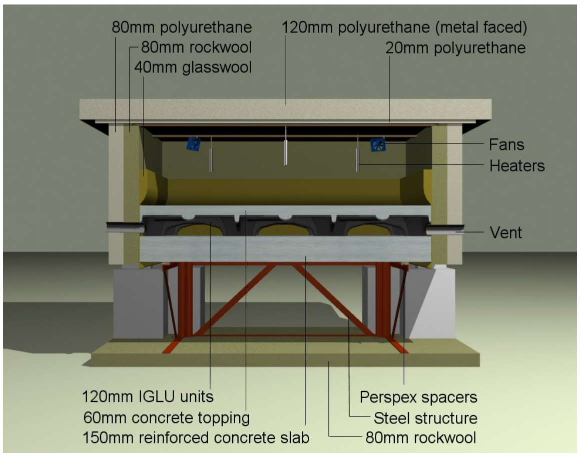


Figure 5, 6: Cavity roof using Iglu modules and position of thermocouples.





Figures 7, 8: Conventional monolithic roof construction composed of three strata: RC slab, “torba” and topping screed.

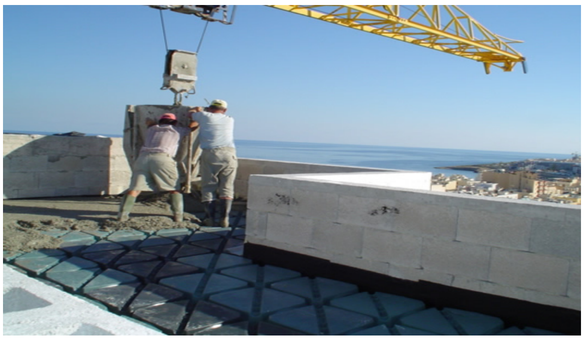


Figures 9: Test rig set-up

Figures 10: Experimental setup in the laboratory.

Vaulted Cavity Roof	Summer	Ventilated
		Non-ventilated
	Winter	Ventilated
		Non-ventilated
Conventional Roof	Summer	Monolithic roof (no cavity)

Table 1: The main scenarios tested.



Figures 11: Actual vaulted cavity system set up with cast in situ concrete being poured over.

A temperature difference was created between the top and bottom of the slab and the temperature at different parts of the slab is measured using thermocouple heat sensors. The experiments were also focused to obtain a good first approximation of the U-Value of the composite slabs, under laboratory conditions [5]. The options ultimately tested are set out in Table 1.

The same setup was also used to test the conventional flat roof construction type in Malta, for benchmarking purposes. This consists of a nominal 150mm reinforced concrete slab, 100mm 'torba' and 100mm concrete screed. This has made it possible to map out the U-values against established values for a conventional slab.

The ventilation options for each system set-up were simulated by inducing a vent-flow speed of 1.1m/s, as exit conditions after frictional losses. This was achieved through three pairs of 65mmØ holes, fitted with motor-operated cooling fans, calibrated with a hand-held anemometer.

5.0 RESULTS & FINDINGS

The temperatures recorded in each test permitted the calculation of the U-value of the entire specimen (Table 2). Furthermore, the thermal conductivity, k, of each physical element making up the specimen was extracted (computed) as shown in Table 3.

Test Type	*Summer*	*Winter*
Ventilated	2.45	4.60
Non-ventilated	3.55	3.60
Screed + 'Torba'	5.24	---

Table 2: Output U-values in W/m^2K for entire specimen.

Individual element	*Thermal conductivity, k*, [W/mK]
Vaulted R.C. Slab	1.38
Flat Screed	1.72
Torba (moist)	2.15
R.C. slab	1.68

Table 3: Itemised thermal conductivity for each material.

6.0 DISCUSSION

From tables 1& 2 above it is evident that the ventilated roof has a lower U-value than the non-ventilated roof, differing by 1.10 W/m^2K. At the same time there is already a significant difference ($1.69W/m^2K$) between the non-ventilated roof and the conventional composite slab. This shows that there is a significant contribution of 2.79 W/m^2K between the ventilated system and the conventional monolithic slab for summer conditions.

On the other hand winter conditions show a thermal reversal, as expected, where greater losses are experienced through the ventilated vaulted space. Hence this suggests that such cavities are to be closed in winter to curtail heating energy losses.

Table 3 refers. The vaulted R.C. (reinforced concrete) slab has a thermal conductivity, k of 1.38 W/mK which is fairly close to the same property for a conventional flat screed of 100mm (1.72W/mK). This is also understandably close.

7.0 TEST RIG CRITIQUE

Effect of variable thermal inertia: It is worth pointing out that the conventional roof slab however has a greater thermal mass than the vaulted roof system. Thus in a long term experimental observation one would have to asses the thermal inertia of the roof composition.

Sensor position: The recycled lightweight polypropylene being around 4mm thick throughout is reinforced by means of structural ribs formed as part of the prefabricated material itself. To avoid any sheltering effect from air movement within the vault itself, the sensor was placed on the ridge of such ribs. This could have distorted the temperature profile, even if insignificantly.

Peak temperatures: The 5no. heat sources inside the test rig were laid out along the diagonals of the 1.5m square set-up. There could have been a margin of error experienced due to the uneven distribution of heat throughout the surfaces.

Laboratory Conditions: For any estimate of the U-value the temperature difference across a hot and cold chamber is needed. In these set of experiments the laboratory conditions were used as the cold chamber. This could have affected the results overall, even if marginally.

Air temperature of ventilated air: By the same reasoning the air temperature of the air intake was also conditioned by the actual laboratory conditions of the day of the different respective experiments. Thus slightly differing results may have been obtained in this respect.

Steady Sate Conditions: These would also hypothetically take longer since laboratory conditions may have been varying over a 24-hour cycle. It is for this reason that in reality a seven day period was allowed for to reach steady state until actual readings were eventually taken.

Sensors availability & calibration: The number of thermocouple sensors was limited by the 18no.channels available on the only data logger available. This set the maximum number of simultaneous readings possible at any one go.

8.0 CONCLUSIONS

It is an established fact today that natural ventilation is one critical parameter for the success of passive cooling. This paper purports to prove just that.

The ventilated cavity for summer conditions has proven to be a significant contribution to convective cooling of the structural slab. The unventilated set-up, if not so effective for direct convective cooling, would provide the much needed shading from solar gains. Also the static air inside the vaulted chambers contributes towards reducing thermal conductivity between the structural slab and the screed topping, especially considering air being such a poor conductor of heat.

In winter it is equally evident that a ventilated cavity looses more heat to the outdoor environment, hence ideally kept closed. Once more the same horizontal cavity acts as a buffer from low night time temperatures in winter.

In conclusion, one solid contribution of this paper is the experimental values obtained for thermal conductivity k, for the individual materials used for the test rig. These standard building materials are still in use today in the Maltese building industry. However these may need further testing, focused on the material properties themselves.

9.0 FURTHER RESEARCH

Scope for further research includes a more refined test rig, such as testing out using a reflective foil between the prefabricated vaulted polypropylene carcass legs and the structural slab, or possibly various insulation materials and thicknesses.

The variation of the height of the vaulted structure is another potential variable to be tested. Cavity heights would require a deeper study distinguishing between laminar and turbulent flow. This could also be extended by testing out for different wind exposures and orientation.

Real life case studies could also be used monitored over at least one year in order to sensitise on-site logging to both diurnal and seasonal variations.

Thermal comfort could also be tested through a subjective study running parallel to field tests. Subjects using such habitable spaces could be interviewed on their preferred ventilation strategy.

Such ventilated vaulted systems could therefore have a significant effect on uppermost air layers of habitable spaces in Malta, especially in dwellings, typically having bedrooms at the upper floors. Night purging is therefore essential not only through such ventilated floors, but also through the habitable spaces themselves. This is deemed to reduce cooling loads considerably. A thorough energy audit assessment of two identical dwellings – one with and one without such ventilated roofs – would go a long way to ultimately prove the efficacy of such systems.

ACKNOWLEDGEMENTS

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