A POST-OCCUPANCY EVALUATION OF ENERGY-EFFICIENT MEASURES IN THE HOUSING SECTOR: A CASE STUDY FOR MALTA

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Abstract: Due to higher demand for housing in Malta, local single-family dwellings, typically terraced houses, are being demolished to make way for maisonettes and multiple storey apartments. This increases the energy demand per square metre that would lead to a greater load on the infrastructure. This paper describes the first example of building an energy efficient housing block that integrates energy efficient measures and renewable energy systems, as a sample of Maltese housing stock working towards a sustainable housing vision.

Keywords: energy efficiency, housing, solar energy, solar water heaters, photovoltaics.

1 INTRODUCTION

The Housing Authority in Malta is constantly being pressured to provide an adequate supply of housing units at affordable prices. Land was not always readily available, hence older dwellings had to make way for new build. In many instances, this led to the quasi-extinction of traditional building features that were reasonably sound moderators of the local climate. As a result modern units and apartment blocks led to a higher demand for heating and cooling in the dwellings. This project aimed at implementing specific features that will not only improve the thermal performance of the building, but will also provide a lower energy intensity value that respects the Environment and Aesthetics.

2 THE PROJECT'S INCEPTION

In its efforts to provide more environment-friendly residences, also known as Sustainable Housing, the Malta Housing Authority has embarked on realising the first energy efficient social housing project in Malta. The block consists of ten apartments spread over three storeys, with a showroom at ground level and an underlying floor of garages at basement level, in the area known as Tal-Ftieh in Birkirkara, Malta. Following an intensive exercise of evaluating all options specifically adaptable for this block, a number of economically-attractive measures were proposed, which were eventually implemented in the course of building the block and thereafter. The proposed measures were grouped into two main categories as those pertaining to the construction phase and those that would be implemented at the finishing stage.

Figure 1 shows the Northern and Western facades of the Block with photovoltaic (PV) modules and some solar water heaters (SWH)visible on the roof. Projecting fin walls between apartments also provide shading from the afternoon sun.

Table 1 gives a summary of the measures that were implemented in this project and the benefits that each of them is expected to produce. It is to be noted that the resulting increase in the cost for implementing these measures amounted to about 5.000 € per apartment.

ITEM NO.	PROPOSAL	BENEFITS
CONSTRUCTION PHASE		
1	Tinted double glazed windows and doors.	Reduce ‘green house’ effect and increase insulation properties thus reducing heat gains/losses.
2	Louvered windows and doors	Reduction of direct sunlight on glass and increase possibility of leaving glass windows open to allow for natural ventilation.
3	Expanded polystyrene insulation for the roof. White wash on roof to increase reflectance.	Reduce heat gain to the building envelope from the roof.
4	Thick expanded polystyrene insulation inserted in the cavity of the external double walls facing south and southwest.	Reduce heat gain to the building envelope from the walls.
5	Increased building height on the top floor	Reduces extreme temperature gradients (microclimate effect) at the uppermost floor.
6	Forced ventilation for the staircase.	Removal of heat from the building envelope (common part).
POST-CONSTRUCTION PHASE		
7	10 no. Solar Water Heaters for apartments.	Save electrical consumption.
8	1 no., 1.5 kW peak, grid connected solar system (for showroom).	Save electrical consumption.
9	2 no. Sun-pipes in the garages’ common areas at basement level	Save electrical consumption in the basement. Reduce lighting costs during the day.

TABLE 1: Energy efficient measures implemented in a first of its kind housing block at ‘Tal-Ftieh’ – Birkirkara, Malta.

Figure 1: Tal-Ftieh Energy Efficient Housing Project, B'Kara-Malta, showing the northern and western facades, the latter with solar shading devices in the form of fin walls. A grid-connected 1.5 kWp PV system and twinned solar water heaters are also partly visible on the roof.

3 ENERGY EFFICIENT MEASURES

3.1 Tinted Double Glazing

Tinted double-glazing was used for doors and windows throughout the block. Tinted glass was preferred to reflective or coated glass, since the latter not only reduces heat transmission but is also diminishes natural light intensity considerably. This could also prompt the occupants to use artificial lighting even during the day; that would partly defeat the scope of an 'Energy Saving Block'. Moreover, double-glazing was used throughout in order to reduce solar gains and minimise energy losses from space heating or cooling.

3.2 Louvers

Typically Mediterranean, the composite louvered window consists of three components. The glazed element allows the passage of sunlight and solar gains, much desirable in winter, yet keeping out the cold winds. The external louvers expel direct sunlight, deterring solar gains in summer, yet allowing a cool breeze in summer. The counter shutters on the inside of the glazed element, apart from ensuring security, completely eliminate both solar components, also providing a sound thermal barrier by the air void between the timber and the single glazing.

Together with double-glazing, the louvers further control unwanted solar gains in summer. They can be lat in by opening them wide open in winter, giving the building all the necessary flexibility of control. This was particularly important to reduce solar gains from a setting sun penetrating the rear bedrooms across west wall glazing in the afternoon. Such louvers shunt the otherwise retained heat, thus minimising the need for cooling at night.

3.3 Roof Insulation

Since in Malta pitched roofs are inexistent, most of the unwanted solar gains in summer occur through flat roofs. These are of a high thermal inertia, considering the relatively monolithic nature, composed of the structural slab, soft stone chippings and counter screed, summing up to over 0.3 m thick and the fact that the mean horizontal solar insolation during the summer months is close to 7 kWh/m^2, the roof slab's surface temperature often rises above the 50 °C mark, with the result that accumulated heat is released over a six to eight hour time lag into the upper floor rooms, typically bedrooms. This causes unwarranted discomfort at night and an accumulated discomfort well beyond the summer season.

Using proper and adequate roof insulation may therefore deter the installation of air conditioning. In the light of such circumstances, based on testing out analysis, calculating U-values and its payback return through practical experience, it was recommended to use low density 75mm expanded polystyrene, laid immediately above the structural slab, yet below the roof screed finish and crushed limestone, better known as '*torba*'. This would serve as an insulating medium to resist heat transfer from the top roof level to the internal ceiling slab, thus lowering indoor air and surface temperatures.

Moreover, it was proposed that the roof surface be painted white as distinct from aluminium-based coatings. The latter are less effective than white coatings at reflecting incoming radiation and reducing roof temperature. A basic rule of thumb is that metallic objects have low emissivity and nearly all other parameters remain high. Roofing materials with high albedo can reflect up to 85% of incident solar radiation, compared to normal surfaces, which may reflect only 20%. White paint is also much easier to clean and cheaper to re-apply afresh.

3.4 Wall Insulation

South facing walls are exposed to the sun's insolation practically from sunrise to sunset. The maximum temperature build-up occurs in the hours around midday, but the effect on the building's interior usually lags behind by a number of hours, depending on wall thickness and cavity width, i.e. the overall thermal mass of the envelope. A way of reducing the impact is by inserting materials that provide resistance to the passage of thermal energy from one side of the wall to the other.

This building had a blank south wall aligning third party property, which may not be built for a number of years. After working the thermal transmittance (U-value) it was recommended to insert a 50 mm thick low density polystyrene as insulating material squeezed tight between the two skins of the double-leaf (2x150mm) masonry wall construction of the south and south-west facing walls.

The reason behind the choice of a low density ($15kg/m^2$) expanded polystyrene (EPS) as opposed to a high density type, is explicitly because the double density type ($30kg/m^2$), attracts a *doubling of the price* too, since it contains double the material. This was also in consideration of the fact that ultimately the difference in U-values was insignificant, namely 0.040W/mK for low density EPS when compared to 0.037W/mK for high density

EPS. Hence an overall better pay-back period is achieved through a more economic given thickness of EPS as an insulating material.

3.5 Building Height of Upper Floor

As a further measure to lower indoor temperatures in the upper floors, it was proposed to increase the top floor height by at least two courses. This would help to increase the temperature stratification within a larger volume of air, thus alleviating thermal discomfort in summer. Considering the fact that the top air layers tend to be warmer, being closer to the roof slab, increasing the floor height detracts the hot air layer from coming closer to the occupied zone of just under two metres. Such a larger volume of air also improves air quality through dilution of pollutants as well as enhances convective air movement when heating the same space in winter.

Although not quantified at this stage, precedent studies by the leading author have already demonstrated the effectiveness of a greater height to width ratio of a habitable space [1]. Traditional Maltese town houses stand manifest to this day towards this end.

3.6 Ventilation in Stairwell

The Maltese Sanitary Laws, dating back to 1936, make specific provisions for adequate (minimum) natural ventilation through good sized openings (typically 160 x 100mm) placed diagonally opposite in a room, circa 270mm below the ceiling. In Malta modern buildings, particularly apartment blocks make minimal use of such available provisions for ventilation, especially in stairwells. This is either because it entails the manual opening or closing of windows or because of other reasons such as dust, noise, insect intrusion. Moreover, wind speeds during summer are generally known to be weak (0.2 –0.7m/s), which would not be sufficient to remove any trapped hot air within the common areas, typically hallways and the stairwell.

Towards this end, each stairwell of this apartment block was fitted with two diametrically opposite extractor fans within the topmost 0.5m from the ceiling. These were complemented with ingress sources of air through louvers at the lower level of the stairwell and hallway. Such fans are set to come on just after sunset and switched off after sunrise, all set on a timer switch.

The low-energy mechanically assisted ventilation, providing an air change rate in excess of 1.5 m/s, ensures the gutting out of the stairwell air and other public areas at night when outdoor temperatures are lower than the indoor air. Preliminary temperature readings indicate a temperature difference of 1.3 – 2.5˚C. The cool air eventually serves as a transitional buffer cooling for occupants, demanding less cooling in the apartments, if any.

3.7 Solar Water Heating

In consideration that Maltese households consume over 60% of their energy for water heating, solar water heating systems were considered as a necessary renewable energy application that saves a considerable amount of fossil fuel electricity, without compromising comfort and hygiene. Otherwise the majority of resident familie would revert to conventional electric boilers to heat water for standard domestic needs.

After standard procedures of compiling specifications, drawings and open tendering, evacuated-tube direct heating solar systems were installed for each apartment with a hot water storage capacity of 150 litres. This is considered as a sufficient storage of hot water for catering for the washing needs of an average family of four persons in Malta.

The systems come with an intelligent digital controller that can programme the amount and time at which cold water could be allowed to fill the tank, besides controlling the thermostat setting and time of switching the electric backup heater. These controls help manage the hot water availability better for the winter season, which is important to minimize the use of the electric booster.

Figure 2 shows 6 out of the 10 solar heating systems installed on the roof. It is clear that some of the systems in the background are raised well above the roof level in order to avoid shading by the perimeter walls. These systems are currently being monitored for at least one year to verify their performance and to monitor the trend of hot water usage throughout the different seasons.

Figure 2: Solar water heating systems installed on the roof of the Sustainable Housing Project at Tal-Ftieh, Birkirkara, Malta.

3.8 Solar Photovoltaic System

Since the building block had a showroom at ground level, it was felt that a suitable energy saving appliance should also be provided for this space. It was concluded that a solar photovoltaic system would be more adaptable than a solar water heating system, since the use of hot water in showrooms would be minimal, while electricity consumption is imminent. A 1.5 kWp system was installed on the roof as shown in Figure 3 and connected to an inverter to allow for grid-connection. The system is also being monitored for a minimum period of one year to provide information on its performance and its proper operation in grid-connected mode, in accordance with users' needs and trends of consumption.

Figure 3: The 1.5 kWp Photovoltaic system, comprising 10no. modules and an inverter, connected to the showroom of the Housing Project.

3.9 Sun Pipes

Sub-terranean lock-up garages in Malta almost invariably require some form of artificial lighting for their common drive-in ramp and often meandering access, since these present an accident prone area and a security hazard. Be it at ground floor or at basement level these are typically planned under the whole block, typically roofed over with prestressed hollow core slabs, thus sealing away natural light. Hence the need for artificial lighting, typically fluorescent tubes or tungsten halogen reflectors left on all day long.

The installation of two sun pipes (or light tubes), 350mm in diameter have introduced natural light into the basement through purposely devised holes through two shaft floors typically dedicated to building services. These come complete with a highly reflective aluminium alloy pipe built in sections, capped with a transparent Perspex dome at the top, terminating with a hemispherical translucent equivalent dome at the bottom. Each sunpipe provides 580 lumens through a straight run of 11.8m. This substitutes an equivalent of 4 no. fluorescent fittings, left on for 24 hrs x 7 days x 365 days a year. Again, this is the first time in Malta that sunpipes are being installed in a public building, namely a social housing project of this kind. An illustration of the installed pipe is shown in figure 4.

Figure 4: One typical sun pipe installed and capped at roof level, running down through the shaft to the underlying garages at basement level.

4. QUANTITATIVE EVALUATION OF BENEFITS

Due to the implementation of the above measures, it is envisaged that the apartments would not need air conditioning during the summer months. This would entail an annual saving of about 2,000 kWh of electricity for cooling per air conditioning unit, which corresponds to a saving of 1.76 tonnes of CO_2 at the Power Station. Moreover, there is a saving from the fact that these units will not be purchased, besides their maintenance and lifetime limitations.

The introduction of the roof insulation would reduce heat gains by 80%, when considering the total roof area of about 500 m^2 and an indoor temperature of 25 °C. Moreover, the fact that the roof is painted white further increases the savings to 11,000 kWh/annum and the overall payback period for applying these measures would be 4.5 years.

The use of double-glazing tinted glass in this building was also analysed on actual orientation and aperture area. The reduction in heat gain as opposed to plain single pane glass amounted to 7,000 kWh/annum and the payback period was found to be 3 years.

As for the insulation of the South facing wall, it was concluded that the heat gain would be reduced by 70% with a payback period of 1.4 years.

The ten solar water heating systems would collectively save an equivalent amount of 25.5 MWh of electricity annually that would have otherwise been consumed in electric boilers. This corresponds to a saving of 22.5 tonnes of CO_2 that would have been produced at the power station to generate the required electricity supply. The payback period for these systems was found to be 3.5 years.

As for the 1.5 kWp photovoltaic system, it would save about 2,000 kWh per year and 1.76 tonnes of CO_2 [3]. Although the payback period at this stage is greater than 20 years, it was felt very important to start introducing such systems on a small scale in the Housing Sector, as a new application that supports sustainability. It is envisaged that the payback period of such systems would be close to 6 years when installed in the year 2015. Since, the cost of this system compared to the total cost of the building is negligible, it was possible to include it at the construction stage and hence the payback period issue becomes diluted if not bypassed.

Similarly, the price of the sun pipes are still high leading to a long payback period, but since they were introduced early in the project, the distribution of costs would buffer this application and the justification of implementing new products in the local building environment becomes acceptable within these boundaries. The two sun pipes would effectively save 0.5 tonnes of CO_2 annually.

5. CONCLUSIONS

Table 2 below summarises the results of applying all the energy saving measures at Birkirkara 'Tal-Ftieh' Housing Project. These are based on preliminary calculations, on-site observations and separate monitoring of similar buildings.

ITEM NO.	PROPOSAL	SAVINGS (kWh Cooling load/year)	CO_2 SAVED (Tonnes/year)	PAYBACK PERIOD (Years)
1	Tinted double glazed windows and doors.	7,000	6.16	3
2	Louvered windows and doors	N/A	N/A	N/A
3	Expanded polystyrene insulation for the roof. White wash on roof.	12,000	10.5	4.5
4	EPS insulation inserted in cavity (ext. walls, south and southwest).	4,700	4.14	1.5
5	Increase building height on the top floor	N/A	N/A	N/A
6	Forced ventilation for the staircase.	N/A	N/A	N/A

7	10 Solar water heaters	25,500	22.5	3.5
8	1.5 kW peak, grid connected PV solar system	2,000	1.76	>20
9	2 no. Sun-pipes in the garages' common areas at basement level	600	0.5	>20

TABLE 2: Overview of energy saving measures, together with their expected savings and payback periods [2].

Further to these preliminary results and indicators for this project, the Housing Authority has already committed itself to follow suite in all new Housing Projects, paying particular attention to roof insulation, double glazing, louvered apertures, rain water storage and solar water heating systems.

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7. REFERENCES

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