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MODELLING AND SIMULATING THE EFFECTS OF THE USE OF INSULATED BUILDING FABRIC IN A MULTI-STOREY MALTESE RESIDENTIAL BUILDING

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ABSTRACT: Although some literature on the benefits of improving the thermal characteristics of Maltese buildings already exists, further research is required in order to quantify the full extent of these benefits. This is particularly relevant when considering that many new buildings are multi-storey complexes whose thermal characteristics differ from floor to floor on a seasonal basis. The research presented in this paper aims to improve the understanding of using insulated compared to non-insulated construction materials in a multi-storey residential building. A building simulation tool was used to simulate the thermal performance of a three-storey building assuming different building fabric scenarios. The scenarios investigated varied between two extremes; a ***low efficiency*** and a ***high efficiency*** scenario. The various measures which differentiate the two scenarios were individually simulated to assess their specific effect on space heating and cooling energy demand and internal temperatures. Results show that compared to the use of non-insulated building fabric, when using the insulated fabric the total building energy demand was reduced by 36% in summer and 32% in winter. These savings are however not uniform across the building and individual improvements tend to effect the building differently based on floor location, season and time of the day.

Keywords: Energy-efficiency; Multi-storey Maltese residential building, Building simulation

1 INTRODUCTION

1.1 Energy efficiency in buildings

Energy efficiency has now become a key priority for all countries, either as part of international agreements or through voluntary environmentally-friendly policies. As a member of the EU, Malta is bound by a number of Directives aimed at increasing energy-efficiency. One of these directives, Directive 2006/32/EC [1], requires that Malta reaches an overall savings target of 9% in energy end-use by 2016.

An important aspect in reaching this and eventually more ambitious future targets is the improvement of energy-efficiency in residential buildings. In Malta, residential buildings account for about 16% of the total final energy consumption, including about 33% of the total electricity consumption [2]. There is therefore a wide scope for intervening in this energy consuming sector. Improving the energy-efficiency in residential buildings can be achieved through reducing demand or through the introduction of renewable energy systems or a combination of both measures. Various incentives introduced in Malta, have been quite successful in increasing the uptake of both energy-efficient appliances and renewable energy systems. Combined the total energy saving from these measures are quantifiable at around 19.5 GWh in 2010 [3]. Excluding the displacement of electrical demand for heating water, however, these measures predominantly target the electrical demand associated with non-HVAC loads (Heating, Ventilation and Air Conditioning). Although a proper breakdown of the energy consumption in residential buildings in Malta is not available and hence the exact space heating and cooling energy demands of Maltese residential buildings are not known (anecdotally these account for 30-40% of the electrical consumption and 20-50% of the gas consumption [4, 5]), it is generally agreed that substantial energy savings can be obtained by improving the building fabric.

Unfortunately, the high premium for living space in Malta, the scarcity and cost of natural building resources [6] and a perceived mild climate [5] has led to a situation where for a long period of time, the efficient use of energy in space heating and cooling was not a priority. It is imperative therefore, that research studies such as this one address such issues by providing data clearly explaining how energy-efficiency in space conditioning results in considerable energy savings.

1.2 Drivers for improving the building fabric

The main driver for improving the fabric of buildings is Directive 2002/91/EC on the Energy Performance of Buildings (EPBD) [7]. The Directive requires that new buildings and buildings with a floor space area in excess of 1,000m^2 undergoing major renovation satisfy the minimum requirements for energy performance (in Malta specified in the *Technical Guidance - Conservation of Fuel, Energy and Natural Resources* [8]). The Directive also establishes the concept of the *Energy Performance Certificate* as a tool to assess and enhance the energy performance of buildings.

Locally, as discussed in Malta's 2nd Energy Efficiency Plan [3], the implementation of the EPBD as a driving mechanism to improve the thermal performance of buildings has been subject to a number of problems related to the perceived financial effectiveness of implementing energy-efficiency measures and the self regulatory aspect of the certification. As Malta is gearing up to the final target of new nearly zero-energy buildings by 2020 (in accordance with the revised EPBD) through various measures [3] including new building regulations, it will be important that the performance and potential savings of energy saving measures are quantified, preferably backed by technical evidence, to encourage investment.

1.3 Studies on the effect of improving the building fabric in Maltese buildings

A number of studies, papers and feature articles have examined and discussed the effects of improving the building fabric in Maltese buildings. A particularly relevant piece of work was that done by Buhagiar and Yousif in [9], who provide a post occupancy evaluation of the energy-efficiency measures in a prototype low-carbon building in Malta with integrated building fabric improvement measures and renewable energy systems. The study examined the measures deployed and gave preliminary results in terms of quantified energy savings of the individual measures for the whole building. Other studies by Buhagiar illustrate the current state of affairs of the Maltese building industry [6] and describe the measures that should be taken to decrease the energy demand due to space conditioning [10], such as applying roof insulation, using double glazing etc.

1.4 Building simulation tool and scope of research

Although the aforementioned studies are useful in giving an indicative understanding of the effect of energy efficiency measures on a building's performance, the complexities involved in modelling the behaviour of these measures for the different floors in a multi-storey building under simultaneously varying conditions (solar gains, outside temperature, shading, HVAC systems output etc.), typically requires the use of a whole building simulation tool to obtain comprehensive results for such studies.

Such a research technique appears to have never been used to model Maltese multi-storey buildings. To address this gap, this research aims to improve the understanding of using different levels of insulation in a multi-storey Maltese residential building through the use of such a building simulation tool.

2 METHOD

2.1 Overview

The energy modelling tool ESP-r [11] is used to model, simulate and analyse the effect of improving the building fabric in Maltese residential buildings, specifically multi-storey buildings. A number of design features, such as double glazing, wall and roof insulation were simulated, first individually and then aggregated together, in order to assess their individual and their combined contribution in terms of energy savings. The simulation was performed for two characteristic weeks; one in February representative of the months when heating is the predominant load and one in July, when cooling is required.

2.2.1 Building modelling geometry

In order to understand the influence different external factors, such as "*level of exposure*" and occupancy have on the effectiveness of fabric improvement measures, two three-storey buildings were simulated. The first building, shown in Fig.1, referred to as the ***Homogeneous*** building was modelled with all floors having geometrically similar window apertures, similar externally exposed faces and occupancy patterns. The building is bound by another building by the east side only (marked perimeter) and all the other faces are exposed to external outdoor conditions.

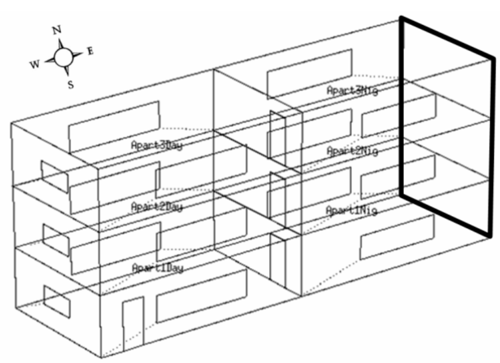

Fig.1 - *Homogeneous* building with identical floors

To facilitate the modelling procedure, each floor/apartment was modelled as two zones, such that each zone groups a particular set of rooms. For all floors, the west facing zone represents the living area, which groups together the living room and kitchen for that particular apartment. Conversely, facing east is the zone, which groups together the bedrooms of each respective apartment. This method of room zoning facilitates not only the modelling of the internal gains but also the thermal control of the building. Annex 1 lists the characteristics of each individual zone.

The second building, shown in Fig.2, referred to as the ***Inhomogeneous*** building, represents a building whose three floors are not identical. The building is similar in size to the *Homogeneous* building but has some differences in terms of windows' sizes, bound faces and occupancy patterns. The ground floor apartment (Apartment GF) is completely bound by another building both from the east and north sides (marked perimeter). The bedroom zone of the middle floor apartment (Apartment MF), is bound by the east and north sides. Finally, the top floor apartment (Apartment TF) is bound only on the east side. Annex 2 lists the characteristics of each individual zone.

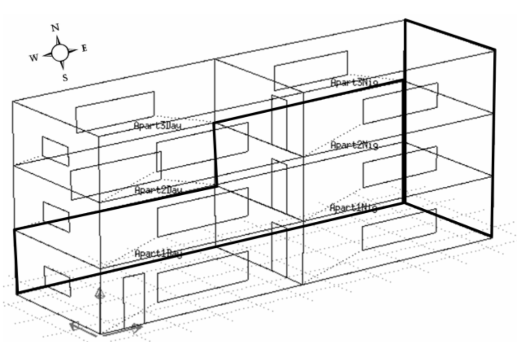

Fig.2 - *Inhomogeneous* building with non-identical floors

During summer, shading was added in the form of external louvers. The louvers were modelled as 40mm thick external blinds placed at a distance of 60mm from each glazing, covering about 70% of the aperture, typical of fixed and moveable shading devices used in Mediterranean climates [12].

2.2.2 Internal heat gains

An important aspect in building simulation is the modelling of the internal heat gains in the building due to occupants and appliances. As discussed in Section 2.2.1 the internal heat gains of the three apartments of the *Homogeneous* building, were assumed to be identical; all representative of a 3 person household. In the case of the *Inhomogeneous* building, the internal heat gains for all three floors were assumed to be different. For the ground floor apartment the internal heat gains profile is assumed to be that of a 2 person household, whilst for the middle and top floor apartments the profiles are assumed those of a 3 and 4 person household respectively. The internal heat gains profiles were modelled using the default values specified by ASHRAE in [13, 14]. Fig.3 shows the internal heat gains of a single apartment modelled to represent a characteristic day in winter. The dashed and the solid line represent the internal heat gains inside the bedroom and the living area respectively.

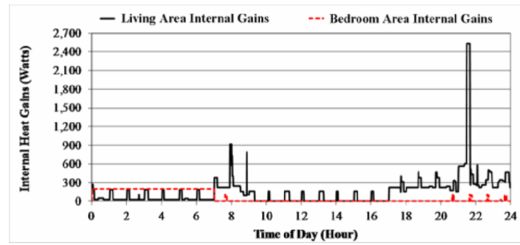

Fig.3 - Internal heat gains for a single apartment

2.2.3 Temperature control inside zones

The temperature control during the heating season was set to maintain the indoor temperature of the apartments between a temperature of 18.5°C and 21.5°C while, the temperature control during the cooling season was set to between 21°C and 24°C. In the case of the cooling season, cooling is provided during both night and day at selected hours, whereas during the heating season, heating is provided during day time only.

2.3 Measures investigated

For both the *Homogeneous* and *Inhomogeneous* building, two scenarios were investigated. A first ***low efficiency building fabric scenario***, representative of a building utilising poorly insulated fabric and which serves as a base scenario against which all measures are compared. This can be considered as representative of the current Maltese housing stock as discussed by Buhagiar in [6]. The second scenario was a ***high efficiency building fabric scenario*** representative of a building utilising insulated fabric. The various measures which gradually transform the low efficiency into the high efficiency scenario were also simulated and analysed individually. The measures investigated are based either on the recommendations present in the *Technical Guidance - Conservation of Fuel, Energy and Natural Resources* [8] or the measures implemented in the prototype building documented by Buhagiar and Yousif in [9]. The individual energy-efficiency measures analysed are as follows.

2.3.1 Insulated *vs*. non-insulated walls

As discussed by Buhagiar in [6], internal space constraints and the scarcity of natural building resources have resulted in the thinning of external façades, with thin air filled cavities inside double-leaf walls of 10mm at best. In contrast with this low efficiency scenario, the fabric improvement measure proposed in this case relies on the use of *Expanded Polystyrene* (EPS) as a form of wall insulation. In simulating externally facing walls the high efficiency building scenario makes use of a 50mm thick EPS insulation inside the cavity between the outer 230mm thick soft limestone block and the inner 150mm thick concrete block face. The introduction of EPS lowers the U-value of external walls from 1.19W/m^{2}K to 0.43W/m^{2}K. A thinner layer of 10mm EPS was also applied to bounded walls, lowering the U-value from 1.89W/m^{2}K to 1.16W/m^{2}K.

2.3.2 Insulated *vs.* non-insulated roof

One of the measures implemented in the prototype building discussed by Buhagiar and Yousif in [9] is the use of roof insulation and the application of a white finished coating to decrease solar gains through the roof of the building. The high efficiency building fabric scenario in this case relies on the use of a 180mm roof insulation board placed between the internal concrete roof slab and the external crushed limestone and lean concrete mix. Contrary to the 4mm dark finished roof felt simulated in the low efficiency building fabric scenario, the insulated roof simulated in the high efficiency building fabric scenario is finished using a white painted 12mm roof felt. The total U-value of the roof is hence reduced from 1.40W/m^{2}K in the non-insulated case, to 0.59W/m^{2}K in the insulated case. Similarly, the solar absorbtivity of the roof is reduced from 0.9 to 0.5.

2.3.3 Double *vs.* single glazing

Rather than using a single "*normal*" glass pane, the high efficiency building fabric scenario in this case relies on the use of an air-filled low emissivity double glazing. The U-value in this case is reduced from 3.73W/m^{2}K to 2.26W/m^{2}K.

2.3.4 Insulated *vs.* non-insulated internal ceilings

An addition to the previous measures is the introduction of intermediate insulated ceilings between floors. The benefits of this measure would mainly be applicable in situations where one of the floors is to be kept at particular conditions (such as the case of a shop/showroom) for prolonged hours of the day, whilst the adjacent floors are not. Similarly to the roof insulation this energy-efficiency measure relies on the use of a 50mm roof insulation board which lowers the U-value from 1.72W/m^{2}K to 1.18W/m^{2}K.

2.3.5 High *vs.* low efficiency scenario

The high efficiency scenario contains all the measures proposed in contrast with the low efficiency scenario which contains none.

3. RESULTS AND DISCUSSION

3.1 Thermal performance cooling season (summer)

3.1.1 Impact on indoor temperatures

Fig.4 and Fig.5 show the temperatures profiles inside the living and bedroom area of Apartment TF, the top floor apartment of the *Homogenous* building, for the different measures investigated. The profiles are for a single day during the simulated period in July. The temperature inside the living area zone is controlled between 07.00-10.00 hours and 15.00-24.00 hours, whilst that in the bedroom area zone is controlled between 24.00 and 07.00 hours. The temperature inside the two areas is uncontrolled during the remaining hours.

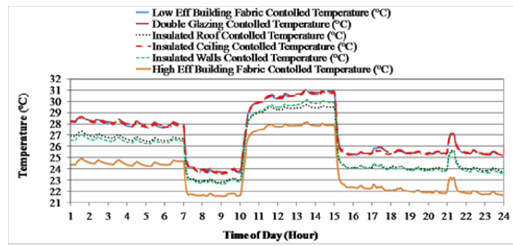

Fig.4 - Temperature profiles for the Living Area TF

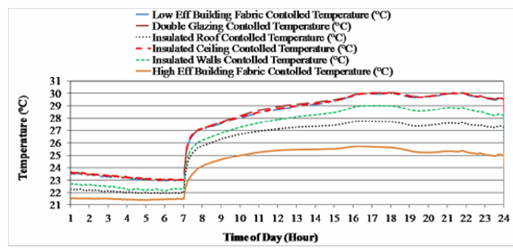

Fig.5 - Temperature profiles for the Bedroom Area TF

Individually the most successful measures are the roof and wall insulation, with the former being slightly better in this specific case. During the late morning and early afternoon, when the indoor temperature is uncontrolled, it can be observed how the different measures influence the peak indoor temperature inside a specific zone. Considering the Bedroom Area TF (Fig.5), the indoor peak temperature inside the zone during the uncontrolled period varies between a low of 25.7°C for the high efficiency scenario to a high of 30°C for the low efficiency scenario with intermediate values of 27.7°C and 29°C obtained for the roof and wall insulation respectively. The high solar inclination during summer which renders roofs the main entry point of solar gains into buildings effectively results in a situation where improving the building fabric of the roof to reduce solar gains is of primary importance.

The profiles discussed are of course valid for this specific apartment, and as will be discussed later diverse measures tend to impact floors differently. Fig.6, for example shows the temperature profiles for the bedroom area of the ground floor apartment, for the same simulation period.

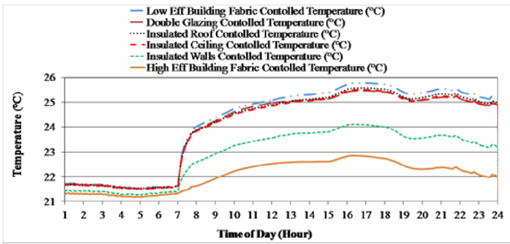

Fig.6 - Temperature profiles for the Bedroom Area GF

During the uncontrolled period it can be observed that the use of wall insulation in this case is again very successful at lowering the peak indoor temperature (24.1°C compared to 25.8°C of the low efficiency scenario). The use of roof insulation has on the other hand no impact on the temperature profile of this zone. The other two measures, that is, the use of double glazing and the insulated intermediate ceilings appear to have no significant effect on the indoor temperature of the top floor apartment and a marginal impact on the ground floor apartment. As expected, the high efficiency scenario which relies on the combined effect of all measures is the most effective in all cases at reducing the indoor peak temperature.

3.1.2 Energy savings

Fig.7 shows the individual and aggregated energy savings of the measures compared to the low efficiency scenario for both buildings for all zones. For the living area zones the results represent the savings obtained during the day between 07.00-24.00 hours, whilst for the bedroom area zones the results represent the savings obtained during night between 24.00-07.00 hours. The savings are based on a week-long simulation.

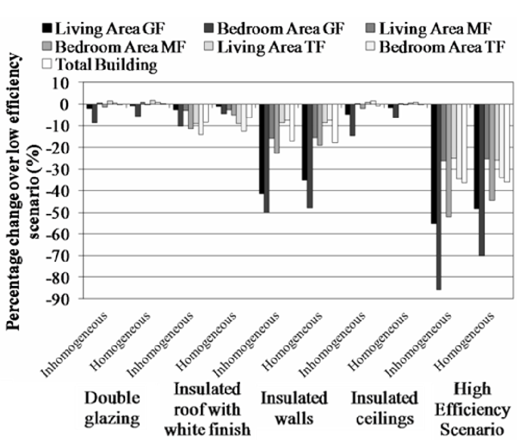

Fig.7 - Energy savings for the cooling season

An important result which can be immediately extracted from Fig.7 is that, whereas changing the "*level of exposure*" and occupancy conditions of the building impacts the savings obtained for any individual floor, the amount of savings obtained for the total building is practically identical for both buildings. For this reason, the discussion which follows, although mainly emphasising the results obtained for the *Homogeneous* building, is also valid for the *Inhomogeneous* building.

3.1.2.1 Analysis on the entire building

On an individual basis, the highest energy savings for the entire building (*approx.* -18% energy demand compared to the low efficiency scenario) is obtained using wall insulation, mainly because the applicable area of intervention is also the largest. In fact, although the energy demand using roof insulation is reduced by only 6%, the specific percentage of energy savings per m^2 of applicable intervention area is practically identical for both roof ($-0.053\%/m^2_{of\ roof}$) and wall insulation ($-0.057\%/m^2_{of\ external\ wall}$). Given the smaller area of intervention this effectively renders roof insulation by far the most efficient measure in summer. Also, considering that the contribution to the total energy savings obtained for the entire building from double glazing and the intermediate insulated ceilings is practically negligible and that the total savings are around 36% it is clear that the overall savings are not simply the arithmetic addition of the savings obtained individually by each measure. Explicitly, it can be concluded that a strong interaction exists between the different measures, which further re-enforces the overall effect. This further demonstrates that a simple calculation of the potential savings achievable without proper simulation is highly unlikely to provide an accurate estimate of the potential savings.

3.1.2.2 Analysis on a floor to floor basis

On a floor by floor basis, it can be observed in Fig.7 how different measures tend to behave differently, both with respect to specific floors and to the time of day, with savings obtained from the proposed measures being higher during night time. In terms of floor location it was generally observed that increasing energy savings were obtained moving downwards into the building, with the highest savings obtained for the ground floor apartment. This indicates that during summer, the thermal performance of the lower located floors improves not only through fabric improvements carried out on that particular floor, but also from fabric improvements effected in the floor/s directly above. The exception is for roof insulation whose savings are highest for the top floor. Insulating the intermediate ceilings is of limited use unless as discussed in Section 2.3.4 a particular floor is not required to have higher cooling energy demands compared to the other floors.

Double glazing is a specific measure which requires a broader explanation. Given the lower U-value of the double glazing one would expect a reduction in energy demand. This is however not the case as the overall space cooling energy demand of the entire building increases by a marginal 0.3%. Moreover, on comparing the individual results obtained for the double glazing scenario for the different floors, it can be observed in Fig.7 that whereas the double glazing effectively reduces the cooling energy demand of the two zones in the ground floor apartment, Living Area GF (-1%) and Bedroom Area GF (-5.6%), the energy demand in the top floor apartment zones, Living Area TF (+2%) and Bedroom Area TF (+1%) increases. In explaining this behaviour it is important to distinguish between the two properties of an energy saving building fabric measure in warm and sunny climates; its main role as thermal insulation between the indoor and outdoor environment and its ability to reduce solar gains transmitted through the fabric into the building. Whereas improving the building fabric through other measures such as roof and wall insulation effectively satisfies both requirements, the transparent nature of the glazing is not very efficient at cutting off solar gains. Gains transmitted through the glass are therefore retained within the zone, increasing the internal temperature and partly off-setting the savings obtained through the lower U-value of the glazing.

Another important aspect which also explains the discrepancy in performance obtained for the different floors in the case of the double glazing scenario, is its interaction with other building fabric improvements. Considering the fact that double-glazing, similarly to all other measures was investigated on its own implies that as discussed earlier, the major entry point of the solar gains into the building in summer, that is, the roof was not insulated. The use of double glazing in the top floor apartment, which due to its location is the floor which is mostly exposed to direct sunlight, effectively tends to accentuate the retention of this solar gain. To test this hypothesis a second simulation was performed using both roof insulation and double glazing. Results obtained confirmed that when both measures are used they complement each other by reducing the space cooling energy demand of the entire building by a further 1% compared to the use of roof insulation alone. Similarly, the individual energy savings for each floor are higher than those obtained for the use of roof insulation alone.

Together with the fact that lower located floors tend to benefit from improvements in the thermal envelope of the floors located above them, the importance of roof insulation as a major entry point of solar gains into a building also explains the high discrepancy in energy savings obtained for the different floors in the insulated walls scenario. In fact, the ground floor apartment shows savings of 4 to 6 times higher than the savings obtained in top floor apartment.

3.2 Thermal performance heating season (winter)

3.2.1 Impact on indoor temperatures

Fig.8 shows the indoor temperature profile for the living area inside the ground floor apartment for all the different scenarios for a single day during the simulated period in February. The controlled period starts at 18.00 hours and during the remaining time the temperature is uncontrolled.

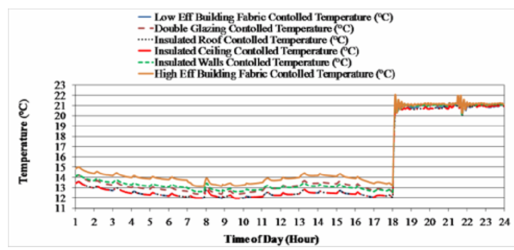

Fig.8 - Temperature profiles for the Living Area GF

It can be observed in Fig.8, that the most efficient measures are the double glazing and the wall insulation. However, in the case of the heating season apart from insulating the indoor environment an important and desirable aspect in ensuring an energy-efficient building is maximising the capture and retention of the incident solar heat. Contrary to the cooling season, in this case the transparent nature of the double glazing ensures that, whilst the internally produced heating energy is efficiently retained inside the building, the incoming solar heat is not cut off and can hence be absorbed. Improving the thermal performance of glazing in winter is a very important measure. In this regard it can be observed that during the uncontrolled period between 12.00 and 15.00 hours the temperature inside the zone increases slightly more in the double glazing scenario compared to the insulated walls scenario. The larger thermal inertia of the walls, on the other hand, ensures that the solar heat absorbed by the walls is released in a slower manner compared to when double glazing is used. This ensures that the indoor temperature remains stable for a longer period.

3.2.2 Energy savings

Fig.9 shows the individual and aggregated energy savings of the measures compared to the low efficiency scenario for both buildings for all zones, for a week-long simulation during February. Similarly as for the cooling season the difference in energy savings in the two buildings, (the *Homogeneous* and *Inhomogeneous* building) is minimal with the overall energy savings for the two buildings being in both cases around 33%. Again only the *Homogeneous* building will be discussed as a representative of both buildings.

3.2.2.1 Analysis on the entire building

Contrary to the cooling period, Fig.9 shows how applying roof insulation has a marginal effect on the energy utilised for space heating whilst the use of double glazing has on the other hand, a profound effect (*approx.* -17% energy demand compared to the low efficiency scenario). The reason rests in the fact that the lower solar inclination implies that the main entry point of solar gains is horizontal through the glazing, rather than vertically through the roof. Introducing wall insulation also provides an appreciable amount of energy savings (-10%), although, the smaller area of intervention required and the higher savings achieved in the case of double glazing makes double glazing a more effective measure during the heating period (-0.03%/$m^2_{\text{of external wall}}$ compared to -0.3%/$m^2_{\text{of glazing}}$).

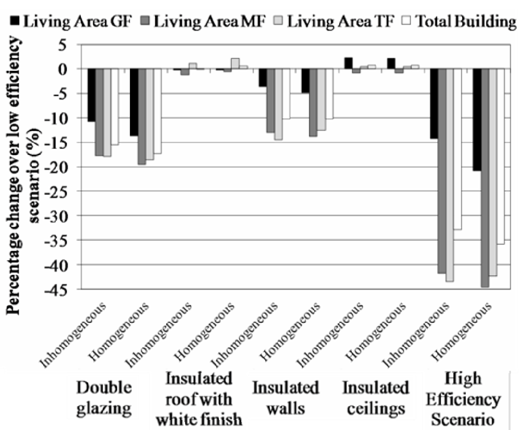

Fig.9 - Energy savings during heating period

As occurs in the cooling season, the combined effect of the savings obtained from the double glazing and the insulated walls do not add up to the total 33% savings, again suggesting a strong interaction between the different measures.

3.2.2.2 Analysis on a floor to floor basis

In terms of the impact of energy-efficiency measures vis-à-vis floor location it can be observed that applying insulated fabric to the building results in the highest energy savings being obtained for the middle and top floor apartments. The ground floor apartment shows an improvement of just around half the savings achieved in the other two apartments. The main reason for this is the fact that no measure was implemented to insulate the flooring of the ground floor apartment; a significant pathway through which heat is lost in winter. An additional simulation aimed specifically at understanding this heat loss pathway demonstrated that, the laying of a 7mm thick carpet on the flooring of the ground floor apartment results in an individual increase in energy savings of the high efficiency scenario of the ground floor apartment of 6%, and a total increase for the whole building of around 3%.

4. CONCLUSIONS & RECOMMENDATIONS

The paper has presented the results of a research aimed at understanding the effects of using insulated fabric in a multi-storey Maltese residential building. The research was conducted on a three storey building using a whole building simulation tool, ESP-r. Different building fabric improvements were analysed first on an individual basis and then on an aggregated basis for characteristic weeks in winter and summer.

Results obtained show that significant energy savings are attainable for the heating and the cooling seasons, 33% and 36% respectively. In both summer and winter, applying wall insulation proved to be very successful with potential savings in the region of 18% in summer and 10% in winter. Double glazing produced more energy savings in winter with around 17% energy savings, whilst roof insulation was effective at reducing gains in summer with a calculated overall reduction for the whole building of 6%. The calculated savings are however not uniform for all floors and different measures tend to behave differently for different floors.

The paper has also shown that the overall savings due to different measures are not simply the arithmetic addition of the individual savings but is a more complex calculation relating to the interaction between the different measures implemented. It is important to note that the findings presented in this research should be interpreted as the results for this specific building type and not as a general rule for the proposed measures. The fabric improvements investigated in this research may lead to different outcomes in other buildings types. Further analysis, aimed at quantifying the potential savings for different Maltese buildings is therefore required.

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ANNEX 1

Dimensions and characteristics of *Homogeneous* building: Each zone Length 10m; Width 6m; Height 2.7m; Total roof area 120m^2

	Externally exposed walls area (m^2)					Glazed area (m^2)				
	South	**West**	**North**	**East**	**Total**	**South**	**West**	**North**	**East**	**Total**
Living Area GF	21.6	14.7	23.0	0.0	59.3	5.4	1.5	4.1	0.0	10.9
Bedroom Area GF	23.0	0.0	23.0	0.0	45.9	4.1	0.0	4.1	0.0	8.1
Living Area MF	21.6	14.7	23.0	0.0	59.3	5.4	1.5	4.1	0.0	10.9
Bedroom Area MF	23.0	0.0	23.0	0.0	45.9	4.1	0.0	4.1	0.0	8.1
Living Area TF	21.6	14.7	23.0	0.0	59.3	5.4	1.5	4.1	0.0	10.9
Bedroom Area TF	23.0	0.0	23.0	0.0	45.9	4.1	0.0	4.1	0.0	8.1
Total Building	133.7	44.2	137.7	0.0	315.6	28.4	4.4	24.3	0.0	57.0

ANNEX 2

Dimensions and characteristics of *Inhomogeneous* building: Each zone Length 10m; Width 6m; Height 2.7m; Total roof area 120m^2

	Externally exposed walls area (m^2)					Glazed area (m^2)				
	South	**West**	**North**	**East**	**Total**	**South**	**West**	**North**	**East**	**Total**
Living Area GF	21.6	14.7	0.0	0.0	36.3	5.4	1.5	0.0	0.0	6.9
Bedroom Area GF	23.0	0.0	0.0	0.0	23.0	4.1	0.0	0.0	0.0	4.1
Living Area MF	21.6	14.7	21.6	0.0	57.9	5.4	1.5	5.4	0.0	12.3
Bedroom Area MF	23.0	0.0	0.0	0.0	23.0	4.1	0.0	0.0	0.0	4.1
Living Area TF	21.6	14.7	23.0	0.0	59.3	5.4	1.5	4.1	0.0	10.9
Bedroom Area TF	23.0	0.0	23.0	0.0	45.9	4.1	0.0	4.1	0.0	8.1
Total Building	133.7	44.2	67.5	0.0	245.4	28.4	4.4	13.5	0.0	46.2